



Review

Defining and identifying strongly sustainable product-service systems (SSPSS)

Philippe Roman^{a,c,d,*}, Géraldine Thiry^{a,c}, Coralie Muylaert^{a,f}, Coline Ruwet^{b,d}, Kevin Maréchal^e

^a Department of Economics and ICHEC Research Lab (IRL), ICHEC Brussels Management School, Boulevard Brand Whitlock 4, 1150, Woluwé-Saint-Pierre, Belgium

^b Department of Social Sciences and ICHEC Research Lab (IRL), ICHEC Brussels Management School, Boulevard Brand Whitlock 4, 1150, Woluwé-Saint-Pierre, Belgium

^c UCLouvain (CIRTES), Rue de la Lanterne Magique 32, Bte L2.04.02, 1348, Louvain-la-Neuve, Belgium

^d UCLouvain, Louvain-la-Neuve, Belgium

^e University of Liège, Gembloux Agro-Bio Tech, Economics and Rural Development, Passage des Déportés, 2, Gembloux, 5030, Belgium

^f Université de Liège, Gembloux Agro-Bio Tech, Passage des Déportés 2, B-5030, Gembloux, Belgium

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ABSTRACT

Product-Service Systems (PSS) are widely recognised as promising models for increasing circularity and sustainability in business, but the extent to which they contribute to sustainability is still debated. While growing and insightful, the literature on PSS sustainability fails to cover all the relevant aspects and to take stock of the ways PSS can be conceptualised as contributing to strong sustainability. We contend that if PSS are to be designed to be strongly sustainable, clear guidance is needed based on both clear normative premises and sound empirical knowledge. Based on systematic and non-systematic literature reviews on the drivers of PSS (un)sustainability and a long-course field work on the development of PSS in Brussels (Belgium), the paper identifies important sustainability challenges that PSS frequently face and that PSS initiatives should address. These challenges are articulated with insights from the sustainable business models literature and anchored in a strong sustainability pre-analytical stance. An original analytical framework based on 5 dimensions (access, substitution, systemic dematerialisation, territorial anchoring and sufficiency) and 15 criteria of Strongly Sustainable Product-Service System (SSPSS) is proposed.

1. Introduction

Given the mounting ecological degradations and threats of our time, it is necessary to rethink the economic system based on capitalist growth. Entering a post-growth era implies rethinking the production and consumption patterns that drive the economy (Cassiers et al., 2019). This requires a thorough review of the business model of productive organisations and the promotion of those likely to be aligned with post-growth macro-objectives. For this reason, identifying, experimenting, and designing sustainable business models is a timely challenge (Boons and Lüdeke-Freund, 2013; Upward and Jones, 2016; Geissdoerfer et al., 2018). Beyond business models, it is “economic models”, construed as integrating the ways businesses are related to their environment and to other stakeholders, that should evolve (Bocken et al., 2019; Hinton, 2021).

In that respect, Product-Service Systems (PSS) (Mont, 2002; Tukker, 2004) have attracted increasing attention in recent years both in academia and in the business world (Annarelli et al., 2016, 2021). Product-service systems are often classified into three categories (Tukker, 2004): 1) ‘product-oriented’ PSS consist in the traditional sale of products with product lifetime prolongation services; 2) with ‘use-oriented’ PSS, the use or functionality of the product is sold instead of the product itself; 3) with ‘performance-oriented’ PSS, organisations sell a performance and the product that supports this performance remains its property. These three sets mark out a continuum between organisations that focus more on the product and those that focus more on the service. Walter Stahel, one of the pioneers of PSS (see Stahel and Giarini, 1989), relates PSS with what he calls the *performance economy*: “If you properly maintain and sell your objects as a service for the longest possible time, then you are part of the Performance Economy.” (Stahel, 2019, p. 66)

* Corresponding author. Department of Economics and ICHEC Research Lab (IRL), ICHEC Brussels Management School, Boulevard Brand Whitlock 4, 1150, Woluwé-Saint-Pierre, Belgium.

E-mail address: philippe.roman@ichec.be (P. Roman).

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And he goes so far as to say that “The Performance Economy [...] is the most sustainable business model of the circular industrial economy because by internalising the costs of product liability, of risk and waste, it offers manufacturers a strong financial incentive to prevent losses and waste.” (ibid.)

Though PSS are good candidates as sustainable business models, the demonstration of their sustainability and of their contribution to transformative economic practices remains to be made (Mont and Tukker, 2006; Kjaer et al., 2018; Roman et al., 2020). First, the type of PSS matters. Offers on the performance side of PSS are generally considered to have greater sustainability potential than on the product side (Tukker, 2004; Tukker and Tischner, 2006; Van Ostaeyen et al., 2013; Pereira and Vence, 2020). PSS sustainability also depends on several conditions, from the type of product under study (see, e.g., Agrawal et al., 2012) to the way logistics is managed (see, e.g., Martin et al., 2021). The type of practices they replace and the degree of product care they entail are other key ingredients of PSS sustainability (see, e.g., Moreau et al., 2020). The contribution of PSS to sustainability is indeed ambiguous and it is seldom critically assessed (Tukker, 2015; Blüher et al., 2020). For example, when it comes to car, bike or e-scooter sharing, it seems that PSS are *a priori* assumed to have high sustainability potential (Dias et al., 2021). But there are still few life cycle assessments of PSS, and their results are mixed (Moreau et al., 2020). Blüher et al. (2020) even mention a possible publication bias in favour of positive sustainability impacts. The English-language literature on PSS therefore oscillates between treating it as a business model among others, susceptible to promoting competitiveness for firms, and a business model which inherently brings sustainable outcomes. Kjaer et al. (2019, p. 3) state that “even though PSS originates from a strong sustainability perspective, a shift in focus from environmental benefits to economic benefits has occurred during the last decade”. Between polar positions lie authors who consider that PSS have the potential to be sustainable but are not *per se* (Mont and Tukker, 2006; Bocken et al., 2019). Coming probably from the desire to push PSS research in the sustainability direction, some scholars have thus proposed the acronym “SPSS” for “Sustainable PSS” (Roy, 2000; Cook, 2014; Vezzoli et al., 2012, 2015). Still, while the expression “SPSS” has been widely used in the scientific literature, its proper and distinctive meaning has rarely been directly addressed.¹ Therefore, what it takes for a PSS to be sustainable (and, so, to be an SPSS) is still unclear, let alone if analysed through a strong sustainability perspective, which we endorse in this paper.²

All these considerations might derive from the assumption, sometimes made implicitly, that certain business models are sustainable *per se* (see, e.g., Stahel’s citation *supra*). Though doubtful, we will not challenge this general assumption, but we will look at one of its specific instantiations: are PSS business models inherently sustainable? And what would it take for a PSS to be strongly sustainable (and so, to turn into an ‘SSPSS’)? Answering these questions requires filling a research gap: while some authors shed light on the potential drifts of PSS in terms of sustainability, on several PSS-specific limitations, and on the counter-performances of specific implementations of PSS, this knowledge is scattered and, more fundamentally, there is no unified reading grid of the joint conditions under which PSS could effectively contribute to

strong sustainability.

Knowledge on PSS sustainability is a little scattered indeed: different methodologies (‘traditional’ LCA, non-traditional LCA, multi-criteria assessment etc.), different types of PSS (product, use, result-oriented, in different sectors and different places ...), different assumptions (type of energy used in production, use and transportation, reference scenario compared to the PSS scenario, perimeter of the study, diversity of environmental effects considered etc.). But at the same time, robust insights can be drawn from the literature provided its exploration is complemented with in-depth field understanding of the realities at stake. All reported sustainability assessments of PSS point to blind spots, but to a certain extent these blind spots can be elucidated and potentially dissipated if a large review is performed. So, the present contribution might be described as sense-making, puzzle-solving and articulating PSS sustainability across a diversity of empirical materials.

The concern underpinning this paper is that by underspecifying what is meant by sustainable PSS, research and cumulative knowledge might be hampered. Another concern is that an increasing number of firms will embrace PSS-like models as a way of diversifying their offers and increasing profits in a seemingly pro-environmental way or as a means of greening their business model, but without careful consideration of potential impacts and likely environmental gains. There are many non-environmental reasons for a business to move to PSS offers, among which increased customer loyalty and regular payments, so it is important that firms be driven to SSPSS as part of a game-changing sustainability move rather than to opportunistic PSS-like offers.

The paper proposes a critical screening tool for scholars and PSS developers (including entrepreneurs and policymakers) to fill the identified gap. This tool consists in a set of attention points that developers and evaluators of PSS initiatives are encouraged to consider (see Appendix F). The pre-analytical vision (Schumpeter, 1954) underpinning the research is anchored in strong sustainability (Upward and Jones, 2016; Bjørn and Røpke, 2018; Banerjee et al., 2020; Brozovic, 2020) and social ecological economics (Spash, 2013; Røpke, 2019). Therefore, beyond the most widely accepted defining elements of (S)PSS, what they have in common and what makes a PSS ‘look like a PSS’, we search for the additional criteria that should be present in order to be allowed to talk about an SPSS. The argument even goes a step further by normatively requiring PSS to be “strongly sustainable”, so what is delineated in the proposed critical screening tool are the defining features of SSPSS (“Strongly Sustainable Product-Service Systems”).

The article is structured as follows. The pre-analytical vision that guided the research is stated in section 2. Section 3 presents the material and methods underlying the proposed critical screening tool. The latter is described and presented as the main result of the study in section 4, as a set of criteria circumscribing what strong sustainability would mean when applied to PSS. Section 5 discusses the results. Section 6 concludes.

2. Theoretical background: strong sustainability, sustainable business models and the variety of traditions of PSS studies

The epistemological approach that underpins the paper is anchored in a “strong sustainability” perspective, which is at the heart of social ecological economics. This perspective (described in section 2.1.) delineates the contours of the screening tool proposed in section 4. To address strong sustainability at the business level, the analysis also relies upon the sustainable business models and post-growth business literatures (see section 2.2.). Alongside a social ecological economics perspective, we adopt an institutionalist approach, and therefore pay particular attention to the variety of understandings and practices referred to in literatures on PSS and germane concepts. This entails opening analysis to both dominant literature on (S)PSS (mostly in English language) and to other pieces of research and expertise that investigate PSS through their potential to transform economic activities towards sustainability (mainly in French language). The latter bring insightful contributions regarding the territorial and institutional factors

¹ This relation between PSS and sustainability is more explicit in the French-language literature, which mostly revolves around “functional economy” (“*économie de la fonctionnalité*”) and “economy of functionality and cooperation” (“*économie de fonctionnalité et de coopération*”). These concepts, which share many of the characteristics of the use- and performance-oriented PSS, are more clearly anchored in sustainability objectives (see section 2.3 for a panorama of the several PSS approaches).

² The “strong sustainability” approach in economics (and other disciplines) postulates that there are absolute limits to the growth of the material and energetic metabolism of economic systems, and critical natural capital must be preserved (see section 2 for more details).

at play when it comes to PSS sustainability. Section 2.3. exposes these heterogeneous approaches and stresses the importance of considering them together to address the (strong) sustainability of PSS.

2.1. Epistemological foundations: strong sustainability and social ecological economics

Ecological economics is a research field born and institutionalised in the 1980s. Sometimes defined as “the science and management of sustainability” (Costanza and Dir, 1991), it gathers research on the interplay between the economy and the environment. It is a rather heteroclitic field with agreement upon some overarching ideas, like the embeddedness of the economy in society and the biosphere and the paramount importance of doing economics “as if Nature mattered” (Røpke, 2004).

The strong sustainability approach is at the core of this school of thought. Strong sustainability, as opposed to weak sustainability, takes it that ecosystems or “Nature”, what standard economists tend to call “natural capital”, is hardly substituted by manufactured or human “capital” (Neumayer, 2003). So, ecosystems should be preserved, pollution minimised, and the exploitation of natural resources drastically reduced. Uncertainty is high and tipping points could be reached soon, which warrants precaution. Consubstantial to the strong sustainability approach are also the ideas that growth has limits (ecological, thermodynamic and social) and decoupling economic growth from environmental impacts is mostly a chimera (Haberl et al., 2020). Such an approach is often related to ecological economics, as opposed to environmental and natural resources economics (ENRE), the latter being more prone to convey a weak sustainability vision. As there has been some porosity between ecological economics and ENRE, some argue that ecological economists should assume a more radical stance, distance themselves from mainstream approaches to economics and embrace a “social ecological economics” approach that is firmly anchored in (very) strong sustainability and heterodox economics (see, e.g., Spash, 2013).

Approaching PSS from a social ecological economics standpoint warrants some prerequisites, among which: “externalities” are not occasional but pervasive and fatal side effects of every production and consumption activity; economic growth inevitably generates environmental impacts, so decoupling has severe limits; economic growth has limits too; rebound effects are pervasive and they should always be accounted for in their socio-institutional settings.

So, adhering to strong sustainability in a social ecological economics perspective justifies not taking for granted that a business model could in and of itself lead to absolute decoupling or resource use reduction. It also requires moving away from company-centred approaches and take an ecosystemic view that considers all the actors that gravitate around the company. Attention should always be paid to the scale of the economic activity under scrutiny, its contribution to macroeconomic growth of output, its material and energetic requirements, and the rebound effects to which it lends itself.

Such a strong sustainability perspective sheds light on the shortcomings of circular economy – of which PSS are often considered an integral part – as it is currently implemented in many countries. These shortcomings indeed provide a cautionary tale against taking new capitalist-compatible circular practices as silver bullets of ecological transitions (Genovese and Pansera, 2021; Bocken et al., 2022). Though promising in terms of dematerialisation of economic activities, it presents several limitations, and it is open to a range of criticisms (Korhonen et al., 2018; Giampietro and Funtowicz, 2020; Corvellec et al., 2022). It generates its own breed of rebound effects (Zink and Geyer, 2017; Figge and Thorpe, 2019; Castro et al., 2022), it is not enough transformative (Clube and Tennant, 2020) and a growing number of scholars argue that a strongly (or authentically) sustainable circular economy must comply with some exogenous imperatives (Hobson and Lynch, 2016). And in addition to efficiency, it should also encourage sufficiency, i.e., practices that incentivise consumers to consume less so that everyone has enough to live well without excess (Bimpizas-Pinis

et al., 2021; Niessen and Bocken, 2021; Bocken et al., 2022). Sufficiency practices for the circular economy regard the general idea of “making do with less” through “refuse”, “reduce” and “rethink” strategies (see Bocken et al., 2022, p. 3–4). In the same vein, a genuinely circular economy cannot be adequately understood through an a-territorial approach (Tapia et al., 2021). More specifically, it requires the exploration of how networks of actors in complex supply chains can cooperate on a territory – understood as a spatially inscribed and socially constructed organisation (Pecqueur, 2014, p. 209) – to make a circular business model viable and enhance its sustainability (Rizos et al., 2016).

2.2. Sustainable business models

Alongside the fast-growing scientific literature on the circular economy, research on strong sustainability in business has been developing over the last two decades. So, strong sustainability pre-analytical visions have already been adopted in the study of business (models) in a way that echoes the content of the present paper.

Sufficiency (or moderation) as a business-driven practice has been theorised (Bocken et al., 2014; Niessen and Bocken, 2021; Sandberg, 2021), investigated in sector-specific (Freudenreich and Schaltegger, 2020; Frick et al., 2021; Gossen and Heinrich, 2021; Gossen and Kropfeld, 2022) as well as cross-sector studies (Bocken and Short, 2016; Bocken et al., 2022). Recent publications have addressed the issues of “post-growth organisations”, “post-growth organising” or “growth-independent or post-growth-oriented entrepreneurship” (Rätzer et al., 2018), and others have tried to delineate what firms might look like from a degrowth perspective (Khmara and Kronenberg, 2018; Nesterova, 2020).

Despite the existence of this flourishing literature, research on ‘green’ or ‘sustainable’ business has arguably only marginally adopted the strong sustainability paradigm. In the present article, we will rely in part on this emergent knowledge carrier to fuel several points of our reflection, in particular the importance of thinking about ‘sustainable’ business models in an ecosystemic way, in their relationship to other business models and other stakeholders (see, e.g., Mont, 2004; Bocken et al., 2019), and in their capacity to induce sufficiency-oriented practices among other economic actors, among which notably consumers (Bocken et al., 2022). What the present article will therefore share with these studies is a desire to connect real-world business practices with the strong imperatives of sustainability.

2.3. Making the most of the constellation of PSS studies

In order to grasp the extent to which (strong) sustainability permeates studies of PSS, it is crucial to explore the several intellectual and practical ‘traditions’ in the broad galaxy of PSS studies, each one with its peculiar relevant insights but with its own blind spots as well. Our framework therefore retains several aspects of PSS and SPSS literatures, but also of the performance economy approach (Stahel, 2010), the “*économie de la fonctionnalité et de la coopération*” approach (economy of functionality and cooperation) (Gaglio et al., 2011; ADEME et al., 2017) and the *économie de fonctionnalité* (Buclet, 2014) in French-language research and expertise. We synthetically present the variety of approaches underpinning our analysis and their main features in Table 1.

Though it appears that some approaches diverge quite clearly, they could fruitfully be thought of as complementary. This is the case, for example, with the SPSS and the “*économie de la fonctionnalité et de la coopération*” approaches: the work on SPSS, which is essentially in English language, comes largely from management, the analysis of “sustainable business models” and engineering or design techniques, and is strongly connected to the literature on the circular economy as a way of making the economy more sustainable. Virtues of SPSS are therefore largely assessed through the prism of their ability to contribute to a ‘circularisation’ of production and consumption.

The “*économie de la fonctionnalité et de la coopération*” (Gaglio et al.,

Table 1
Relevant literature strands in the PSS galaxy.

Name	Relevant references (indicative)	Relevant definition
Product-service systems	Goedkoop et al. (1999)	“A marketable set of products and services capable of jointly fulfilling a user’s need. The PSS is provided either by a single company or by an alliance of companies. It can enclose products (or just one) plus additional services. It can enclose a service plus an additional product. And product and service can be equally important for the function fulfilment.” (Goedkoop et al., 1999)
Sustainable-product service systems (SPSS)	Vezzoli et al. (2012), Vezzoli et al. (2015)	“An offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a ‘unit of satisfaction’), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the economic and competitive interest of the providers continuously seeks environmentally and socio-ethically beneficial new solutions.” (Vezzoli et al., 2015).
Performance economy	Stahel (2010, 2016, 2019)	“A performance economy goes a step further ((than a circular economy)) by selling goods (or molecules) as services through rent, lease and share business models. The manufacturer retains ownership of the product and its embodied resources and thus carries the responsibility for the costs of risks and waste. In addition to design and reuse, the performance economy focuses on solutions instead of products, and makes its profits from sufficiency, such as waste prevention.” (Stahel, 2016)
Économie de fonctionnalité (Functional economy)	Buclet (2014)	“(…) the underlying idea (...) is that the value of the product for the consumer is based on use value rather than exchange value. One does not buy an object but what it can be used for, these pioneers of the economy of functionality tell us.” (Buclet, 2014, p. 3, authors’ translation).
Économie de la fonctionnalité et de la coopération (economy of functionality and cooperation)	Du Tertre, IEEFC (Economy of functionality and cooperation European Institute)	“The economy of functionality and cooperation consists in providing companies, individuals or territories with integrated solutions of services and goods based on the sale of a performance of use or a use and not on the

Table 1 (continued)

Name	Relevant references (indicative)	Relevant definition
		simple sale of goods. These solutions must allow for a lower consumption of natural resources in a circular economy perspective, an increase in the well-being of people and economic development.” (Website IEEFC)
		“The dynamics of co-production by providers and beneficiaries of solutions linking, in an integrated way, products and services in order to meet the expectations of households (B2C) or companies (B2B) integrating new environmental and social requirements” (Du Tertre, 2008, authors’ translation)
Access-based consumption	Bardhi and Eckhardt (2012) (based on Durgee and O’Connor, 1995)	“We define access-based consumption as transactions that may be market mediated in which no transfer of ownership takes place. The consumer is acquiring consumption time with the item, and, in market-mediated cases of access, is willing to pay a price premium for use of that object” (Bardhi and Eckhardt, 2012, p. 881, p. 881)

2011; ADEME et al., 2017), on the other hand, emphasises the capacity of economic actors in a territory to cooperate in order to identify the needs to be met and to propose resource-saving solutions based on performance-based contracts. In that respect, the “economy of functionality and cooperation” has in its DNA territorial cooperation, local anchoring and the narrowing of material loops. The quality of work (du Tertre, 2013), the reflection on needs and territorial relevance of offers all play a key role in this approach while remaining mostly absent from other approaches to PSS, which is quite detrimental to the search for genuinely sustainable functional initiatives (Roman et al., 2020). Another important French-language school of thought, the “economy of functionality” (“l’économie de (la) fonctionnalité”) (Bourg and Buclet, 2005), is part of industrial ecology, which again clearly supports its sustainability objective (Buclet, 2014; Serra, 2018; Sidoli, 2017). But these schools of thought are hardly cited or referred to in the international literature on PSS.

So, while the link between PSS and sustainability is often ambiguous in the (English-language) PSS literature, this ambiguity in relation to sustainability is less evident in the French-language literature on “économie de la fonctionnalité (et de la coopération)” (EF(C)) and “économie de fonctionnalité” (EF). Though EF(C) and EF literatures have similar characteristics to the (use- and performance-oriented) PSS literature (sale of a use or performance rather than of a product, dematerialisation, retention of ownership of the good by the organisation etc.), they differ in that they more clearly pursue a sustainability objective. They also pay particular attention to territorial issues (how economic agents coordinate, including with governmental institutions, to identify needs and satisfy them) and adopt institutionalist approaches (notably regulation theory and convention theory).

3. Material and methods

The aim of the paper is to propose a critical screening tool (see section 4) built upon several knowledge carriers. The tool results from the mobilisation of a broad field of knowledge on (S)PSS through 1) systematic literature review complemented by integrative reviews, focusing on how sustainability is defined or characterised in (S)PSS/functional economy/access-based consumption studies and their impacts on sustainability; and 2) field-based qualitative illustration and qualification of the scope and limits of PSS, and of their potential unsustainable drifts. The intention is to bring these various materials together to produce a screening tool for the assessment of whether a given PSS contributes to strong sustainability.

3.1. Literature review: under what circumstances are PSS (un)sustainable?

The theoretical background presented above shapes the literature review in several respects: types of sources explored, keywords chosen, and eligibility criteria for our final selection. Most sources analysed belong to the prolific English-language PSS literature. Given the breadth of references to be explored, we opted for a systematic literature review, completed – at the margin – by an integrative review. In parallel and given the relevant institutionalist and territory-oriented contributions of the less widely cited French-language literature, key articles from this knowledge carrier were selected. The less extensive nature of French-language literature on PSS and sustainability, as well as our knowledge of the field, have allowed us to conduct an integrative review of these sources.

To circumscribe sustainability assessments in the English-language PSS-related literature, the systematic literature review was based on the *Preferred Reporting Items for Systematic Reviews* (PRISMA) flow diagram (Moher et al., 2009). The PRISMA flow diagram includes four phases: identification, screening, eligibility and inclusion. The present review seeks to identify the different ways in which the issue of sustainability of PSS is addressed in the broadest possible literature. So doing and combining this review with the integrative review as well as with our in-depth field knowledge of PSS, we hope to delineate the main dimensions of sustainability that can help us discriminate between strong and weak sustainability versions of PSS.

The systematic review was conducted with a single search engine (Scopus) for two main reasons. Firstly, Scopus is among the biggest databases of peer-reviewed literature, and it is widely used in PSS and circular economy systematic reviews.³ Secondly, scientific journals referenced on Scopus encompass a sizeable share of the PSS literature: among the top 10 journals publishing on PSS identified in Lee et al. (2018), 9 are referenced on Scopus. Moreover, the Scopus search was complemented by a Google Scholar alert that was consulted for four years.⁴

To be as relevant as possible and consistent with the social ecological economics posture detailed in section 2, we decided to exclude journals whose scope was not related to economics, management studies, consumption studies, psychology, or production systems. Specifically, since social ecological economics shows that the model *per se* (and therefore the technological dimensions that underlie it) does not necessarily entail strong sustainability (because of rebound effects, cost shifting or problem shifting effects, among others), we have only considered research fields and disciplinary approaches that address the PSS model beyond its technical or technological dimensions. Following an institutionalist perspective, the focus was on journals and articles that explicitly embed

the technical aspects of (S)PSS in their social, environmental and/or managerial context. These approaches, while acknowledging the important contributions of the engineering literature and often drawing on it, nevertheless place the analysis at a different level and question the sustainability of the model beyond its technical or technological underpinnings.

In addition, since relevant terms related to PSS are numerous (see section 2.2) and include several dimensions that are not specific to the PSS economic model itself ('circular', 'functional society', 'dematerialising', 'resource-efficiency' etc.), an extended keyword research would bring up too many articles. It would be too impractical to sort through the relevant pieces, so the systematic review was limited to the set of widely used concepts that are analogous to PSS.

Accordingly, and taking stock from the sustainable business model literature and from the variety of approaches to PSS (see Table 1), the search words were chosen to encompass the different expressions referring to economic models based on consumption without ownership and provided by a professional organisation and not by an individual (which distinguishes it from other models such as the sharing economy or collaborative consumption). This comprises "product-service systems" (also written "product service systems"), "sustainable product-service systems" (also written "sustainable product service systems"), "functional economy" and "access-based consumption".

Bearing in mind that the paper aims at analysing sustainability assessments or appraisals of PSS, the words "impact" OR "analysis" OR "evaluation" OR "assessment" OR "appraisal" were added in the articles' titles (see appendix A for the detailed research key). Altogether, this research brought up 89 journal articles.⁵

Among these 89 records, abstracts and keywords were screened. Based on several rounds of collective discussions within the research team, the papers were sorted into three categories that were deemed relevant: those out of scope, i.e., not addressing the sustainability analysis of PSS neither in the title, nor in the abstract (category #1); those apparently within the scope, i.e., assessing PSS, providing criteria delineating the sustainability of PSS (category #2); and those whose focus was not directly aimed at gauging PSS sustainability, but whose purpose or research angle, as presented in the abstract, might potentially be of interest to a reflection on the appraisal of PSS sustainability (category #3). While the first category was directly excluded from further enquiry since these papers are considered out of scope ($n = 33$), papers in categories #2 ($n = 34$) and #3 ($n = 22$) were kept for full and in-depth reading. After reading papers in categories #2 and #3, 26 papers were selected through the systematic search (see Appendix B).

Due to the limits of keyword research, the systematic review was complemented by an integrative review consisting in a non-systematic and qualitative search strategy, which combines ideas from different fields. Snyder (2019) stresses the relevance of this type of review when it comes to creating new frameworks or theories by criticising previous ideas: "the purpose is usually not to cover all articles ever published on the topic but rather to combine perspectives and insights from different fields or research traditions" (Snyder, 2019, p. 336). This integrative review encompasses pieces of literature not automatically identified in Scopus but deemed relevant based on the authors' expert knowledge and extensive reading. This led us to add 14 English-language records to the review (see Appendix C for detailed references).

Besides the systematic and integrative reviews of English-language references, another integrative review was conducted on the French-language literature on PSS and sustainability. This review, which aims to be representative of the French-language approaches to functional economy rather than exhaustive, encompasses 10 references (see

³ Annarelli et al. (2016, 2021) also restricted their review to Scopus.

⁴ The keywords for the Google Scholar alert were "product service system" and "économie de la fonctionnalité" (in French). The alert has been running from January 2018 to February 2022.

⁵ As of 22 February 2022.

Appendix D for detailed references).⁶

In total, 50 papers were eventually kept in the final scope. The papers selected after extensive reading are based on an empirical analysis of existing PSS (and not fictitious cases), and/or they offer a substantive discussion of empirically observed factors that drive the sustainability or unsustainability of PSS. Fig. 1 presents the stages of the review.

The 50 papers were read in-depth and qualitatively analysed through inductive coding, oriented by the strong sustainability pre-analytical vision. For each of them, underpinning perspective(s) on sustainability were identified. Such perspectives were characterised according to the type of dimensions the authors considered in the assessment of sustainability. Particular attention was also paid to what was missing in the analysis (although generally pointed out as important aspects of strong sustainability): did the paper account for possible rebound effects, cost shifting, or problem shifting, for instance? How important was the territorial anchorage dimension? Did the paper address sufficiency as a lever to PSS sustainability? Answering these questions for each paper allowed us to characterise several conceptions of sustainability in relation with PSS.

3.2. An immersive dive into the Brussels Region's PSS ecosystem

In addition to the insights from the literature review, the paper draws on empirical material collected through a long-term immersion in a set of SPSS initiatives. More precisely, we spent four years (2018–2021) studying SPSS in the Brussels Region (Belgium) with an eye on territorial embeddedness of SPSS. We endeavoured to grasp SPSS offers in their complex socio-institutional and spatial contexts, thus adopting an ecosystemic approach to business development (Moore, 1993, 2006; Isenberg, 2011). Moore (1993) refers to 'business ecosystem' as the set of interactions and co-evolutions between firms and their business environment, including competitors, suppliers, partners, political authorities, legal frameworks, federations as well as the – actual and potential – consumers to whom the firm addresses its activity. The ecosystem concept helps grasp the complexity of the SPSS-firm context and the dynamics of change and innovation underpinning the extent of their effective contribution to (strong) sustainability. Sustainable business model and PSS scholars have long emphasised the dependency of PSS performance and sustainability on virtuous territorial embeddedness and supporting socio-institutional contexts (see, e.g., Bocken et al., 2019; Mont, 2004).

In this ecosystemic perspective, 58 semi-structured interviews were conducted with a diversity of actors of the ecosystem related to the surveyed SPSS initiatives: entrepreneurs, employees, clients, suppliers, civil servants in environment and business support departments, political staff in charge of the economy in Brussels, sustainability consultants, SPSS experts in support organisations/trade unions, finance and bank sector representatives in charge of the development of green innovations, and academic experts. We used as similar interview guides as possible across interviewees in each category of actors, with variance

across actor categories. All interviews were transcribed and discussed among the researchers' team (see Appendix E for details on the organisations and sectors interviewed).

It is important to note that cases were selected because they implemented and/or promoted a PSS approach (mostly use-oriented) with an explicit ecological focus (they can therefore be called 'SPSS'). All investigated SPSS (except the library) indeed participated in programs aimed at steering the circular economy and/or the functional economy (i.e., referring to the more commonly used term *économie de la fonctionnalité* in French, as mentioned above) in the Brussels Region. They might thus be described as pertaining to a collective movement to green the regional economy which comes along with its specific, well-known and used set of incubators, finance channels, networks, consultants etc. Most studied PSS operate in B2C, but some of them also have B2B activities. B2C and B2B activities are not explicitly distinguished in the present paper (and potential differences are not systematically investigated) because to the best of our knowledge, the dimensions, criteria and relevant questions that emerge from our analysis are valid both in B2C and B2B (albeit possibly with variation). The adaptation of the screening tool to explicitly B2B or B2C settings is left to future research and to the appreciation of experts and practitioners.

The ecosystemic standpoint that underpins the research (see section 3.2) allowed us to draw fine-grained insights not only from micro-level actors (consumers and businesses) but also from meso-level regional actors and institutions (finance providers, public services, incubators etc.).

It should also be made clear that the interviews were not conducted with the primary and explicit aim of investigating the sustainability of SPSS initiatives, but rather to understand the factors of their development (or absence thereof). However, early on with the first exploratory interviews and meetings and throughout the whole research process, the testimonies, observations and cross-checking of data have attracted our attention to the issue of the sustainability of PSS. That is why this fieldwork, beyond its initial purpose, brought several insights and lessons about the potential pitfalls that SPSS may encounter in their quest for sustainable economic transformation at a regional level. The analysis process that was conducted to draw lessons from fieldwork slightly departed from traditional systematic coding since we progressively consolidated the insights through several rounds of discussion within the research team, in a spiralling manner.

In summary, the fieldwork detailed above provides relevant insights with regard to several aspects. Although this empirical material was not specifically designed for the present paper, transcribing the interviews, analysing and discussing the results among authors (even when carried out for other research purposes) has provided good qualitative knowledge of the organisations studied and their ecosystems. Such familiarity made it possible to search elements that best illustrate and/or qualify the results generated by the literature reviews. The empirical material is thus mobilised here with the purpose of supporting the results of the literature review, in several ways. Firstly, it illustrates some of the mechanisms, realities and facts highlighted in the literature reviewed in the paper. Secondly, it helps put in perspective, from a regional perspective, the internal conditions of PSS sustainability that are frequently put forward in scientific literature (what is needed to make a given sustainability element of SPSS effective?). Thirdly, it allows us to identify certain features of territorial embeddedness as necessary for strong sustainability of PSS (what kinds of territorial interactions are conducive to SSPSS?). Altogether, the empirical material will serve to enrich and give a more concrete substance to the screening tool (and its constitutive elements) that the paper intends to provide, as exposed in the results section.

⁶ Several reasons explain that these 24 references (that we consider relevant) were not found by the Scopus search. First, 10 of them belong to a French-language literature and were therefore not found in Scopus, since our search key was in English. Second, for some papers among the 14 English-language papers included in the review, but not found in the Scopus search, their title, abstract or keywords did not include "analysis" OR "Assessment" OR "evaluation" OR "appraisal" OR "impact". For others, their title, abstract or keywords did not include "Sustainable Product service system" OR "Sustainable Product-service system" OR "Functional economy" OR "Product service system" OR "Product-service system" OR "access-based consumption", while the content of the paper was though addressing issues related to servicizing in relation with sustainability. For a few of them, expressions in the title, abstract or keywords did not perfectly match our own search key (for instance, "assessing" was not included since our keyword was "assessment"). Finally, a few of them were not recorded in the Scopus database.

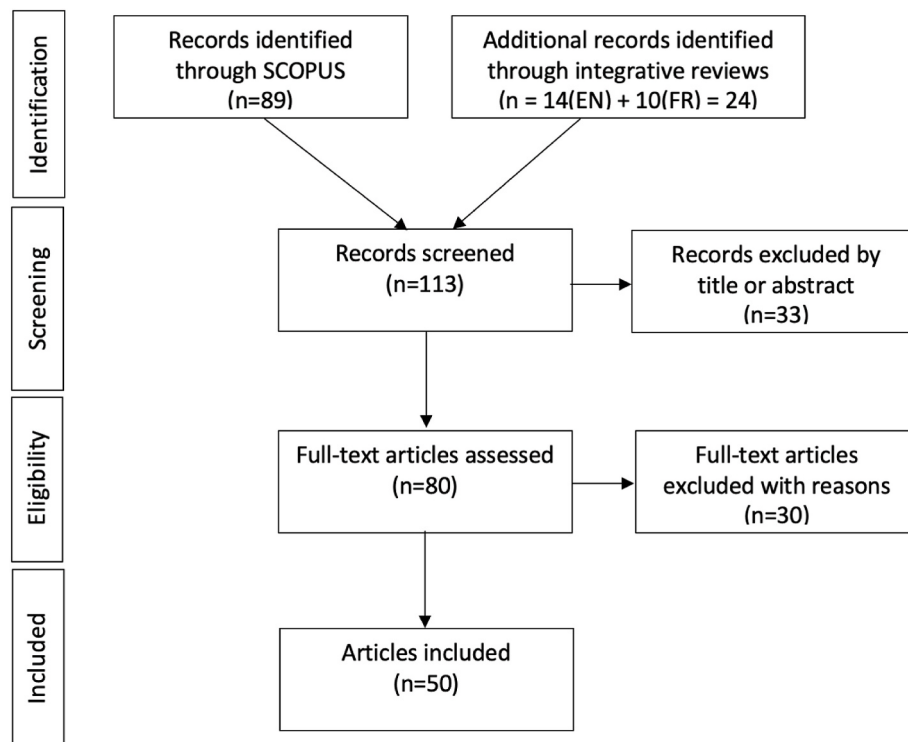


Fig. 1. Systematic review flowchart.

Source: Authors, based on Moher et al. (2009)

4. Results: what it takes for PSS to be *strongly* sustainable

4.1. How is sustainability of PSS assessed? Meta-lessons from the literature review

A first and noteworthy aspect to underline is that the number of papers presenting clear and robust results on the sustainability of PSS based on empirical data is quite limited. In their systematic literature review, Van Loon et al. (2021) state that “it is remarkable that product design strategies for circular economy [...] and product-service systems or other types of circular business models are usually not considered in the LCA studies.” (p. 1) They indeed identify only 6 papers on PSS sustainability. In another literature review, Barquet et al. (2016) selected 17 papers deemed relevant to extract factors of PSS sustainability. Many papers propose a sustainability assessment methodology adapted to the peculiarities of PSS and include a real-world proof-of-concept to illustrate how their approach might be implemented. But their empirical content is too mean and the proposed methodology too experimental to count as a robust contribution to empirical knowledge about the sources of (un)sustainability of PSS in real life settings.⁷ Therefore, as justified in the methodological section, several articles in our systematic literature review have been discarded after close reading (n = 30).

A second lesson is that the approaches to and assessments of sustainability are still heterogeneous in terms of system boundaries, studied impact(s), presence of quantification of impacts etc., as demonstrated in Blüher et al. (2020). Depending on how sustainability is conceived and assessed, the criteria of what would be a sustainable PSS vary. Though, while heterogeneity of methods could lead to significantly contrasted results, we still observe that whatever the method used, PSS are assessed

either as not worse environmentally than traditional sales, or as more virtuous. Only in a few studies are PSS potentially less environmentally desirable than sales (see, e.g., Martin et al., 2021). Among the 6 papers Van Loon et al. (2021) put in the category “traditional product with circular business model assessed” (i.e., assessing PSS offers), no one concludes that a PSS leads to higher environmental negative impact than traditional sales. Lindahl et al. (2014) as well find with 3 case studies of Integrated Product Services Offerings (IPSOS) that PSS (both use-oriented and result-oriented) tend to have better environmental performance than traditional sales. But close attention must also be paid to potential rebound effects of PSS at system scale (Kjaer et al., 2018, 2019; Castro et al., 2022). When PSS help save money, one must ensure this money is not spent in (more) impactful products or services (for a sense of how sharing can create a money rebound, see Warmington-Lundström and Laurenti, 2020 on peer-to-peer boat sharing). Unfortunately, rebound effects are known to be multiple and sometimes powerful, and they concern efficiency measures (Brockway et al., 2021), sufficiency practices (Sorrell et al., 2020) and circular consumption as well (Ottelin et al., 2020), which calls for critical systemic thinking. This also requires thorough understanding of the multiple and complex interactions between actors in business ecosystems, which vary in their support for the sustainable development of PSS (see Roman et al., 2020).

Our own assessment of the available literature and field cases tends to indicate a similar result, namely that PSS offers have the potential to be more resource-efficient than their traditional sale counterparts, but realisation of such potential depends on a series of conditions. The aim is therefore to contribute to the identification and articulation of these conditions in the characterisation of “strongly sustainable PSS”. It is also worth noting that result-oriented PSS tend to be granted higher resource decoupling potential than use-oriented PSS (Manzini and Vezzoli, 2002; Bartolomeo et al., 2003; Matschewsky, 2019). Finally, attention must also be paid to the scenario(s) PSS offers are compared to. As an illustration, renting baby prams is shown through LCA to have lower environmental impact than owning and disposing of it when no longer

⁷ The point of several papers is to develop new assessment methodologies and to illustrate their use with a case study. So, case studies are conducted only with illustrative purposes, and their results should be taken firstly as illustrating the relevance of the proposed methodology (see, e.g., Song et al., 2021).

needed (Kerdlap et al., 2021), but the comparison might turn not as favourable if the reference scenario is the pretty usual informal practice of giving or lending the pram one owns to a relative or friend after use.

A third lesson is that though relevant and providing a fair share of PSS environmental assessments, 'traditional' Life Cycle Analysis (LCA) has been repeatedly shown to be ill-suited to such non-traditional models as PSS (Gehin et al., 2009; Amaya et al., 2014; Doualle et al., 2015; Guyon et al., 2021), which might explain a certain multiplication of PSS sustainability assessment proposals in recent years (Amaya et al., 2014; Doualle et al., 2015; Blüher et al., 2020). The main challenges faced in applying LCA to PSS are determination of the reference system, functional unit and system boundaries (Kjaer et al., 2016). As Laurenti et al. (2016) observe, traditional efforts to assess the environmental benefits of new production processes (such as LCA) are generally framed around a single unit only, they are focused on one object, and they "usually (...) do not take into account that those single units are embedded in a much larger complex sociotechnical system, subjected to dynamic interactions with causal links and responses (feedback loops) from many socio-aspects, technical-aspects and economic-aspects over time" (p. 382), a fact that Blüher et al. (2020)'s review confirms. PSS have indeed the property of extended value-adding network (Glatt et al., 2019). A similar point was made by authors who show the importance of socio-spatial contexts in the performance of innovations for sustainability (Allais and Gobert, 2019), in particular when it comes to PSS (Allais and Gobert, 2016). They also warn against monodisciplinary sustainability assessments and reductionist quantitative approaches.

In sum, the reviewed literature makes clear that there is a need to look at the broader picture, beyond per-unit and relative decoupling, to systemic and absolute resource decoupling (Kjaer et al., 2019), which requires avoiding burden-shifting between lifecycle stages (does the impact reduction during production or use give rise to an increased impact at another stage of the product's lifecycle?) and impact shifting between sectors (does the impact reduction in one sector give rise to an increased impact elsewhere?), and mitigating rebound effects (does the reduced impact or monetary cost generated by a PSS give rise to gains that are used in environmentally detrimental ways?). There is therefore a need to go beyond the analysis of single objects and to consider supporting goods and services (infrastructure, buildings ...) and their impacts in a holistic way (Kjaer et al., 2018; Costa Junior et al., 2019). A good part of the literature also warrants in-context and qualitative appraisal of the sustainability potential of PSS. Mont (2004) had already proposed to open the analysis of PSS to "value system management" instead of the firm or the supply chain alone, by looking at community-based sharing systems from a multi-stakeholder perspective.

4.2. Sustainability challenges for PSS

It is a fact that PSS display features that contribute to making it a sustainable business model, like the incentive to provide long-life, robust and eco-conceived products. But they also have specific pitfalls that may call into question their potential for sustainability in certain circumstances. We identify three main sustainability risks.

Firstly, to genuinely enhance sustainability, PSS need to replace other more resource-intensive provisioning systems (Kjaer et al., 2019; Matschewsky, 2019). This is the issue of 'substitution'. Kjaer et al. (2019) highlight that "in a reality of growing demands, secondary (reused/remanufactured/recycled) products are often sold *in addition* to primary (new) products, resulting in environmental impacts of both the primary and secondary production." (ibid., p. 3). In the mobility sector, one PSS offer in Brussels is positioned as a complement to usual mobility by proposing, for example, the use of cars for a one-way trip to the airport, for a one-time business trip or for a one-way trip to a party in the city. Another offer is positioned as a substitute for car ownership. Even though these two offers propose a PSS mobility offer linked to the same product – a car –, their communication (urban complement or substitute to a personal car), the price structure (pay-per-use per minute or

subscription basis with payment per kilometre) or the car pick-up and drop-off system (in an urban area or at a neighbourhood station) can position them either as a complement or as a substitute, which entails distinct impacts on sustainable mobility.

Secondly, as goods are supposed to travel from user to user along a path involving several intermediaries (warehouse, repair centre, remanufacturing plant, hygiene and safety checks, repackaging ...), PSS are prone to logistics difficulties (likely to threaten financial viability) and to high transport energy costs (Besch, 2005; Khumboon et al., 2009; Allen Hu et al., 2012; Zamani et al., 2017; Muñoz López et al., 2020; Johnson and Plepys, 2021). More energy may be needed to move goods than in traditional sales, especially if the loop is geographically large, the users far apart and far from the company's premises (Behrendt et al., 2003; Mont, 2004). It is therefore important to ensure that the loops are not only closed but also as local as possible. Transport is indeed often a key dimension of the impacts of PSS assessed through LCA (see, e.g., Zamani et al., 2017; Amasawa et al., 2020; Martin et al., 2021). It can even make use-oriented PSS emit more GHG than traditional sales (Mont, 2004; Martin et al., 2021). This points out to the importance of minimising the distance between users, point-of-delivery and warehouses, and choosing (as well as encouraging consumers to opt for the use of) low-impact transportation modes. In addition, when PSS come with increased preventive and corrective maintenance, this might induce increased transportation from service provider to customer and increased related environmental impacts (Khumboon et al., 2009). For this reason, to minimise impacts, a tool library in Brussels preferred to expand its business area by replicating its operations in another place rather than increasing its geographical reach with spatially expanded logistic. On the one hand, consumers must travel to the tool library to pick up and return the tools. On the other hand, the tools are maintained, repaired and parts are replaced in the library's workshop.

Thirdly, and this matters with subscription offers more than with pay-per-use, PSS might reinforce consumerism and increased turnover of goods, for several reasons. Many consumers use PSS offers to get access to an increased pool of things, or to be able to (temporarily) possess the last fashionable thing, or to test products before buying. Social equity concerns apart, PSS might enable some people to access previously unaffordable devices that are energy consuming (ex.: tumble dryer), and so the new practice allowed by the PSS might replace less impactful ones. Consumers may feel entitled to swap clothing garments frequently if they have unlimited access to a clothing library or a subscription with a fixed number of items but with unlimited swaps. So, in a way, PSS have the potential to accelerate psychological obsolescence (Hou et al., 2020), to fuel new needs or desires, and to run against sufficiency.

In a nutshell, such environmental sustainability risks can be summed up with the idea of PSS potentially creating longer and faster product loops. It is therefore important, beyond their well-documented potential contribution in terms of dematerialisation, to make sure that PSS offers are locally anchored, that they are conceived as substituting (rather than complementing) existing offers, and that they come along with (or, even better, impel) sufficiency practices both in business practices and in consumers' lifestyles. In addition to these sustainability dimensions, it is also self-evident that the sustainability of any PSS *a priori* requires that providing access to products (or to a bundle of products and services) be feasible and viable. Before the sustainability dimensions of the PSS can be appraised, it is thus necessary to first consider the suitability for 'PSS-isation' of the product under scrutiny.

Based on 4.1 and 4.2, we identify the building blocks of the SSPSS screening tool as being access, substitution, systemic dematerialisation, territorial anchoring and sufficiency (see Fig. 2).

4.3. Defining SSPSS

The definition and list of criteria proposed here are to be seen as constitutive elements of a tool that could be used *ex ante* and *ex post*. Ex

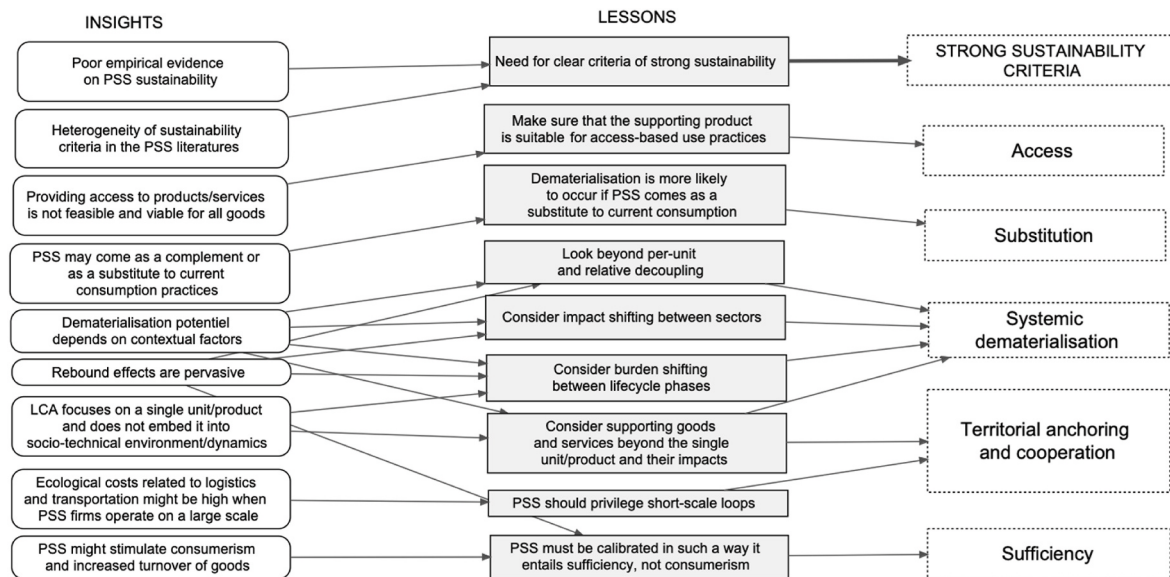


Fig. 2. Building blocks for a SSPSS screening tool.

ante, the tool would serve for screening PSS offers with high likelihood of displaying good sustainability performance (which can be assessed ex ante and/or ex post with the help of other tools). Ex post, the screening tool could help identifying the potential levers of change to be activated in case PSS prove not (or not sufficiently) sustainable. As the definition of SSPSS is tailored to PSS business models, it is a shortcut to the main “dos and don’ts” for PSS developers, a set of guidelines, a checklist of some of the most important elements to be kept in mind in order to maximise the chance of reaching high levels of environmental performance. It does not provide a turnkey method for developing a sustainable PSS, nor a method for empirically assessing the sustainability of existing PSS, but a set of guidelines to keep some of the most frequent ‘sustainability drifts’ at bay.

As already delineated in the previous section, based on the literature review, case studies and strong sustainability background, several dimensions appeared as pivotal in defining a strongly sustainable PSS: access, substitution, systemic dematerialisation, territorial anchoring and sufficiency. Although they are all relevant to design or identify SSPSS, only the first one (access) is peculiar to the PSS business model, the other four being of a more generic kind. Other sustainable business models might integrate requirements such as reducing materials and energy use along the supply chain or implementing a sufficiency approach. However, due to their distinctive operating mode, PSS do specifically require keeping an eye on substituting standard purchase practices, ecological efficiency of the supply chain (specifically reverse logistics), in-depth cooperation of territorial actors/stakeholders and sufficiency orientation. We argue that those are *sine qua non* requirements for a real contribution of PSS to strong sustainability. They are explained in more depth below.

4.3.1. Access

An SSPSS is first about providing access to products or a bundle of products and services (Table 2). Substituting access for sale is what is common to many definitions of (S)PSS, though not all (see the first category of PSS in the dedicated typology). This may be through rental or leasing, and through pay-per-use or subscription (or a mix of the two) arrangements. Before the ecological sustainability dimensions of the PSS are addressed, it is necessary to wonder whether the product is practically suitable for ‘PSS-isation’. This is about the very relevance and viability of a PSS offer. Even though there is little (if any) definitive *a priori* impossibility to create a PSS with any product in any sector, some goods arguably lend themselves more easily to access-based

Table 2

Criteria and relevant questions for the ‘access’ dimension of SSPSS.

Dimension of SSPSS	Criteria	Relevant questions
Access	Non-ownership	➤ Is it suitable and convenient to provide access to the product? ➤ What are the challenges of renting/leasing/sharing the good?
	Functions	➤ What are the functions performed by the offer? ➤ What (basic) needs does it meet? ➤ Does the PSS enrich the offer beyond the (material) product?
	Logistic challenges	➤ Can the transport challenges of providing physical access to the product be accommodated in a viable way?

Source: Authors

consumption/use than others. Failing to recognise this fact might impair the practical feasibility and financial viability of the PSS and could also deteriorate its sustainability potential (with negative feedbacks on the other dimensions of SSPSS). For instance, the suitability of providing access to instead of selling products might be questioned when demand is highly seasonal and/or highly dependent on factors that are essentially exogenous to the population’s activities. While the problem of ‘peak load’ demand and potential over-investment in stock to cope with peaks should not be an overriding argument against PSS, it should though be taken seriously in terms of feasibility. As for the Brussels object library, the rooftop cargo boxes that are borrowed during school vacations and remain in the company’s inventory the rest of the year. Then the risk of unavailability of the good might increase, unless the PSS company invests in an oversized stock of products to be able to face peak demand. There are therefore clear potential trade-offs between providing reliable access to such seasonal/one-off-use goods through an increase in the fleet of available items and both financial viability of the organisation and environmental sustainability. This can apply to subscription-based clothing libraries, which may feel the need to reassure customers by indicating the available stock of clothing items.

In addition, some goods do not lend themselves to multiplying users because they are charged with meaning and affection and are objects of attachment. This is surely the case with children’s cuddly toys, but it can also matter when it comes to clothes, cars or motorcycles. The large extent to which people value privately owning such goods has amply

been demonstrated. As far as private cars are concerned, “control, certainty, reliability and flexibility” but also status-seeking explain a good part of the value attributed to the good (Moody et al., 2021). This goes a long way to explaining why carsharing does not take off more rapidly despite its ecological and financial potential. These arguments should not be taken without a grain of salt, because cultural traits can evolve and what is invested with personal or social meaning can change over time. To overcome this barrier, some clothing libraries offer their clients the opportunity to buy the clothes they have become attached to.

Another access-related aspect to consider is that, alongside and sometimes in addition to access to an asset, SSPSS emphasise a range of services that provide a relevant response to the needs being supported. These services can also contribute to a more informed and sufficiency-oriented use of the product (for example through consumer advice or preventive maintenance to avoid breakdowns). This is a distinctive criterion of SSPSS, which sets this model apart from other circular or sustainable approaches. This criterion goes to the heart of the organisation’s business model. In a way, an SSPSS should involve much more than accessing a product. Depending on where access takes place and how it is organised, access-based consumption can contribute to increasing social ties, multiplying low-energy socialisation opportunities, increasing cooperation between provider and user (cf. section 4.3.4) etc. This is what one tool library in Brussels does, offering training in the use of tools such as hedge trimmers, woodworking tools or renovation-related machines. In doing so, the organisation ensures the correct use of the machines, facilitates access to these machines by training the users, and creates social links by offering users a space for exchange and advice on their work.

Finally, as far as access is concerned, feasibility and practicality of moving products around is another key determinant of the relevance of introducing a PSS. What if the product is very heavy and/or impractical to remove from one’s home and to bring to someone else’s? The importance of logistic challenges in PSS is emphasised in Allen Hu et al. (2012), but also in Besch (2005) concerning office furniture. The very nature of the good might therefore make it difficult (and consequently resource-intensive) to multiply users and use cycles during its lifetime.

A promising way of circumventing this issue is to design goods for greater modularity and increasing potential to be reused by a given user, at a given place. This is what a company of wooden modules in Brussels endeavours to do: the modules are easy to assemble and dismantle, without the need for specific professional tools for the simplest projects, and they can provide a wide range of furniture services: bench, table, sideboard, partition, bookcase etc.

4.3.2. Substitution

An SSPSS should also represent a sustainable and long-lasting alternative to the sale of the product in question (Table 3). One of the major advantages of a sustainable PSS offer compared to similar but different models such as renting or the collaborative economy is that it aims at a change in consumption and in the relationship to consumption, which means that customers stop buying certain products in favour of one-off rental or subscription. If access to a library of clothes or shared vehicles makes it possible to increase one’s textile consumption or travel without any substitution, then the offer does not lead to absolute

dematerialisation of the economy, but rather contributes to reinforcing the impact of consumption (Kjaer et al., 2018). This criterion makes it possible to exclude rental offers that have no effect on the actual practices of consumers. Renting a pedal car on the seaside does not replace the purchase of such a good, so it can hardly claim to have contributed to greater sustainability of the economy. In the case of clothing libraries, dresses rented out for special occasions allow consumers to stop buying dresses that they will wear only a few times. In this case, there is substitution. Other clothing library offers provide a wardrobe supplement, between one and three extra garments each month, meaning that the offer will always be a complement to the pre-existing wardrobe. In Brussels, among the most often rented out objects in a wide-ranging (in terms of product diversity) objects library are cotton candy machines and bouncy castles, goods that would probably not be purchased by individuals anyway. More subtle cases include, as mentioned in section 4.2, a mobility offer in Brussels positioned as a complement to usual mobility by proposing, for example, to use cars for a one-way trip to the airport or for a one-way trip to a party in the city. Evidence of substitution of private cars by car sharing schemes remains somewhat mixed, with studies demonstrating some replacement provided public infrastructures are adapted to this new mobility option (Firnborn and Müller, 2012).

Furthermore, some consumers may be tempted to experiment with a PSS offer simply to test products before buying them. The offer would then not have fulfilled its role but would serve as an auxiliary to dominant consumption practices. Allais and Gobert (2016) show there is such a risk of “rebound” (renting to test before buying and/or inducing new demand) in the case of a rental service offer for small household equipment (Eurêcook). This criterion can be understood as a requirement that the proposed innovation be accompanied by exnovation⁸ of certain forms of production and consumption. When this requirement is fulfilled, impact reduction can be sizeable, like with access-based consumption of household appliances: Wasserbaur et al. (2020) identify GHG emission reduction potential of about 30% in EU with shared access to washing machines.

To be truly relevant, substitution should take place with long lifetime products. Displacing consumption of a resource-intensive good with access to goods frequently replaced because of misuse or lack of eco-design does not go far in terms of sustainability. Hence the importance of considering whether the PSS extends the lifetime of the product (Tasaki et al., 2006). The literature presents mixed results, but some results in the textile sector are promising: a PSS for Merino wool t-shirts intended for use by the British Ministry of Defence as an alternative to the purchase of synthetic t-shirts is environmentally interesting provided the garments have multiple lifecycles thanks to maintenance and repair (Bech et al., 2019). This aspect of substitution interacts directly with the ‘systemic dematerialisation’ dimension (see next sub-section), but also with cooperation (and by extension trust among stakeholders and knowledge on how to wisely fulfil a need) and sufficiency.

4.3.3. Systemic dematerialisation

Then, substitution must be achieved with the objective of a systemic dematerialisation of economic activity (Table 4). This requirement is sometimes referred to in the literature as “material and energy efficiency along the life cycle of the product” or “design for environment” (Barquet et al., 2016) or “resource strategy” (Tunn et al., 2019). An SSPSS must prevent the effects of pollution transfer, impact-shifting and rebound effects by considering the entire life cycle of objects and being aware of the systemic interrelations between practices (a thing the ‘business

Table 3
Criteria and relevant questions for the ‘substitution’ dimension of SSPSS.

Dimension of SSPSS	Criteria	Relevant questions
Substitution	System displacement	➤ Is the PSS a substitute for the sale of a less environmentally efficient material product?
	Quantity reduction via long lifetime products	➤ How long is the product expected to last and to stand as a substitute for other consumption?

Source: Authors

⁸ “Exnovation refers to the processes of destabilisation, decline and abandonment of industries, technologies, business models and practices that are carbon intensive and/or raise other systemic sustainability issues (environmental, socio-economic, urban, etc.).” (<https://exnovation.brussels/en/concept-exnovation/>).

Table 4

Criteria and relevant questions for the ‘systemic dematerialisation’ dimension of SSPSS.

Dimension of SSPSS	Criteria	Relevant questions
Systemic dematerialisation	Degree of materiality of the offer	➤ How material is the PSS? ➤ What are its material and energetic requirements?
	Circularity and lifecycle reasoning	➤ Does the organisation manufacture and/or is supplied with eco-conceived products? ➤ Does the organisation promote resource-savvy use of its products? ➤ How far is the organisation committed to managing the least impactful possible end of life of the goods?
	Impacts of logistics	➤ Are the production cycles of the goods short? ➤ Do consumers make long and frequent journeys to access the goods? ➤ Is the whole life cycle of the product designed to use energy efficient devices?
	Immaterial practices	➤ What is the share of immaterial practices (human relationships, services etc.) that come with PSS delivery? ➤ Does the PSS require social/community involvement? ➤ Does the organisation promote human relationships that substitute for consumption-based needs fulfilment?

Source: Authors

model ecologies’ approach might help achieve, see [Bocken et al., 2019](#)). It has been shown that a commercial offer, however environmentally attractive it may be at the time of use, can be accompanied by strong impacts (sometimes increased compared to a standard offer) either upstream of the production chain or downstream. Cloth diaper-as-service is a better option than disposable diapers, but provided it is implemented “at large scale, using efficient continuous batch washers for sanitizing the diapers” ([Hoffmann et al., 2020](#), p. 1), so that water and energy needs are limited. It might be the case that PSS foster closed loop mechanisms with greener end-of-life of products, and they contribute to prolonged product life cycle with incentives for suppliers to design robust products ([Blüher et al., 2020](#), p. 18). But the quantitative importance and reliability of occurrence of such effects remain uncertain.

In the case of PSS, research often points out to the delivery/distribution phase in the lifecycle of the product/service as a sustainability game changer. As explained and documented in section 4.2., it may be financially optimal to distribute the various supply chain operations according to access to cheap labour and/or resources, but the distance products travel (both to the clients and back to the suppliers) and the way they are moved weighs heavily in the final environmental balance. Hence the need to know very precisely the withdrawal and return habits of consumers and their most frequent mode of travel, but also to optimise the logistics chain, particularly in the “last mile”. This is required so as not to cancel out by increasing physical flows and energy requirements what can be gained elsewhere by intensifying the use of goods. As soon as in 2003, [Behrendt et al. \(2003\)](#) had already cautioned against this risk: “environmental strain caused by extra transport because of the many users has to be taken into account. From a certain break-even point onwards, such costs could be so high that any environmental improvement will be cancelled out.” (*ibid.*, p. 16).

Finally, promoting immaterial practices is likely to be instrumental to enriching PSS offers in a way that contributes to its dematerialisation. A good illustration of this point is provided by a Brussels-based project

that allows children to rent a bike for 10 years at a low cost, with the possibility to exchange the bike as often as needed while children grow up. The parents sign a contract thereby committing to take care of the bike, to come to bike maintenance and to learn how to take care of it. This extends the lifetime of the bikes and for ten years there is a substitution, without having the children owning a bike. The bikes are owned by the company and have a longer lifetime because of the cooperation between the children, their parents and the project mechanics who take care of maintenance. These ‘shared’ bikes benefit many more children than private ones since they do not remain stored for long. Public libraries, although not generally considered as PSS actors, shed another interesting light on this dimension. Beyond lending books, they have over the course of their history become ‘third places’ with diversified services, attentive to the needs of sometimes underprivileged publics (as the British IDEA stores illustrate). While retaining the book as a medium, they have reinvented their missions by multiplying the ways in which they bring written culture to audiences that are sometimes far from it. They also remain places of socialisation around the book object, for example through reading clubs, and it is even argued that they serve as key “social infrastructure” ([Klinenberg, 2018](#); [Van Melik and Merry, 2021](#)).

4.3.4. Territorial anchoring and cooperation

It is widely recognised in the PSS literature that a successful (S)PSS is based on territorially anchored cooperation along the entire value chain aimed at internalising externalities ([Table 5](#)). This criterion is closely linked to the previous one (n°3). It has been shown that a close relationship with partners is a key factor in the performance and sustainability of PSS ([Lindahl et al., 2014](#)).

In addition, limiting impacts throughout the life cycle of the product or value chain is made easier if the actors proposing the PSS solution cooperate closely and over time, including with actual and potential users, in a geographical area that limits the size of the material loops ([ADEME et al., 2017](#); [Roman et al., 2020](#)). The actors should ideally share the objective of providing a relevant and sober response to a finely analysed need and be remunerated in accordance with their qualitative contribution to this objective (and with their capacity to reduce the negative impacts of the envisaged solution, called externalities) rather than according to the quantity of inputs they deliver. This criterion reflects a very important part of the economy of functionality and cooperation approach: a relevant handling of the customer’s needs requires a cross-section of views between various actors and a cooperation that transcends sectors.

This dimension also highlights the contradictions of a kind of PSS that would intensify the use of objects by organising long and complex loops (e.g.: after the use of a piece of clothing by a consumer in country

Table 5

Criteria and relevant questions for the ‘territorial anchoring and cooperation’ dimension of SSPSS.

Dimension of SSPSS	Criteria	Relevant questions
Territorial anchoring and cooperation	Upstream/downstream cooperation	➤ What is the depth and breadth of cooperation with stakeholders in the supply and value chains?
	Internalisation of a large range of externalities	➤ To what extent does enlarged cooperation allow to shoot many targets with the same stone?
	Territorial grounding	➤ What is the depth and quality of integration into the local economic and social fabric? ➤ What is the quality of cooperation with local institutions and government?

Source: Authors

A, the piece would be washed in country B, then repaired in country C, then sent back to the company's warehouses in country D before being used by a consumer in country E). Allais and Gobert (2016) argue that geographical and cultural proximity are key enablers of the functional economy.

As pointed out by Scheepens et al. (2016), the good itself is not sustainable, it depends on the context, hence the role of public authorities, especially regional ones, to provide infrastructures and regulations that make the greener alternatives attractive. It is also important to create stakeholder networks (Mont, 2004; Devisscher and Mont, 2008) or "communities of practice" among stakeholders, i.e., "a common space allowing questions, experiences, knowledge to be shared." (Allais and Gobert, 2016, p. 57).

According to the *économie de la fonctionnalité et de la coopération* framework, cooperating at a territorial scale (especially local or regional) helps moving from selling goods to providing solutions or performance related to a broader set of goals. The company Urbanéo has moved from selling urban equipment (bus shelters, stop posts, etc.) to providing integrated sustainable mobility services, including the eco-design of equipment, its maintenance and participation in the development of intermodal mobility (ADEME et al., 2017, p. 82–84). Such performance offers are only possible through close collaboration with local authorities and mobility operators and through deep understanding of users' needs.

4.3.5. Sufficiency

Lastly, an SSPSS aims to meet identified needs in as relevant a way as possible and is explicitly based on a sufficiency approach (Table 6). This is about putting the notions of 'need' (Doyal and Gough, 1984) and 'sufficiency' (Sandberg, 2021) at the centre. To be truly sustainable, a PSS, like any other business model, must aim to meet real social needs rather than 'artificial needs' (Keucheyan, 2019), and it must avoid fuelling consumerism through the unbridled production of new wants/needs. The idea of sufficiency implies a reflexive approach to the act of consumption, allowing us to ask the questions: why and for whom do we produce and consume? Other reviews on PSS sustainability mention this idea, like Barquet et al. (2016) who identify "promote behaviour change for customer and PSS provider" as one of their five sustainability factors for PSS. Interestingly, they include education and behaviour change not only on the part of the customer but also on the part of the provider: "a new mindset about product responsibility and ownership should be developed" (p. 438). Van Loon et al. (2021) confirms that environmental impacts in circular economy depend on consumer behaviour, and consumers have a key role to play in mitigating circular business rebound effects (Castro et al., 2022).

As mentioned above, a PSS can easily lend itself to unsustainable implementations that consist in promising unlimited access to many goods in a "zapping" mode, thus reinforcing the turnover of objects and their psychological obsolescence. An object library that provides access

to a large number of objects (some of which one would never have expressed a need for) and to all the latest technologies would risk contributing to consumerism and various forms of obsolescence. There are many examples of PSS or consumption without possession of luxury items, and they can be blamed for sustaining one of the main drivers of consumerism and its many environmental impacts: ostentation (also called positional consumption). Finally, it is becoming increasingly clear that sufficiency is an essential component of any productive system that is sustainable in terms of energy and materials, if only for its role in counteracting rebound effects (IPCC, 2022). Recent work highlights the diversity of ways in which companies can promote sufficiency-oriented practices (Niessen and Bocken, 2021).

4.4. From dimensions, criteria and questions to a definition of SSPSS

Gathering and articulating the constitutive dimensions detailed above gives rise to the following definition of Strongly Sustainable Product-Service Systems, defined along the five dimensions (access, substitution, systemic dematerialisation, territorial anchoring and sufficiency):

"A Strongly Sustainable Product-Service System (SSPSS) consists of providing access to products or a bundle of products and services as an enduring alternative to the sale of the products in question. The substitution is made with the explicit objective of a systemic dematerialisation of economic activity. The model is based on territorially anchored cooperation along the entire value chain, aimed at internalising externalities and responding to identified needs in the most relevant way possible. SSPSS initiatives are explicitly part of a sufficiency approach."

Such definition should not be taken as something definitive and/or comprehensive. This is just a way to synthesise what we consider the main elements of (un)sustainability in PSS development (see Appendix F for a presentation of the full-length SSPSS screening tool). Even though this is not the focus of this article (and this might be the subject of future research), one might argue that there are synergies between the five dimensions identified to be constitutive of SSPSS, which could enhance the relevance of the definition. As an illustration, one might argue that moving towards a territorially anchored sufficiency-based circular economy would ease some of the logistical constraints (and associated environmental impacts) associated with the need to supply an ever-increasing variety of goods in an ever-shortening timeframe. So, sufficiency and territorial anchoring would be jointly instrumental to systemic dematerialisation. As another example, strong territorial anchorage would probably make a sufficiency-based PSS more acceptable and virtuous as it could be accompanied by a multiplication of informal social links and increase mutual trust among PSS stakeholders. Such synergy could counteract a possible drift of PSS towards ever more advanced systems for monitoring users' practices and the objects made available to them, particularly through the Internet of Things. Even though it could offer good performance in terms of product lifetime extension (better preventive and curative maintenance), such a scenario of 'high-tech PSS', reminiscent of "circular modernism" (Bauwens et al., 2020), would certainly pose a series of serious problems from the point of view of strong sustainability and societal desirability (increased control by a few large service-providing companies, technological headlong rush, surveillance of consumers and invasion of their privacy, etc.). Thus, relying on strong synergies between dimensions of SSPSS could lead to both sustainable and more "convivial" forms of PSS (see, e. g., Kerschner et al., 2018).

5. Discussion

To begin with, we should not be misunderstood about the scope of the proposed framework. We do not provide ready-made answers to the sustainability of PSS. PSS differ according to their sector, the type of good offered in access, their business model (product, use or result-oriented), the socio-political and institutional context within which

Table 6
Criteria and relevant questions for the 'sufficiency' dimension of SSPSS.

Dimension of SSPSS	Criteria	Relevant questions
Sufficiency	Impact on consumer and provider culture	Are the offer and its marketisation conducive to questioning demand and challenging the quantity of consumption?
	Promotion of immaterial practices	Does the PSS provide access to goods in a way that promotes interpersonal contact and socialising opportunities?
	High quality prescription	Does the PSS overcome 'consumer sovereignty' to convince clients that getting access to high-quality products is the right thing to do, and it is worth the price?

Source: Authors

they are developed etc. So, there is ample room for applying the assessment criteria we propose in a flexible manner.

We do not claim either to have identified the relative and quantitative contribution of the selected constitutive dimensions of PSS to strong sustainability. Only case and context-sensitive expert knowledge will make wise use of the proposed approach and put the emphasis on the most relevant criteria in each situation. As an illustration, it could be argued in a strategic approach that sufficiency should be temporarily given a minor role in SSPSS offers in order to reach a broader clients' base and to achieve wide-ranging acculturation to non-ownership practices. The framework is therefore not a substitute for environmental impact assessment tools such as LCA, but we believe it could be usefully implemented in conjunction with such tools.

Beyond these general disclaimers, there are obvious methodological limitations to the way the SSPSS definition and framework were constructed. First, the number of case studies upon which qualitative insights were drawn is small, and the ability of these cases to highlight the most important sustainability pitfalls in PSS implementation is not guaranteed. Case studies in other sectors could have revealed other elements. This limitation is mitigated by the literature review, which contains several case studies whose findings were triangulated with our own case studies.

Second, the literature review was conducted only in English-language (and, to a lesser extent, in French-language) research communities, potentially leaving aside other realities identified in other research streams/traditions than the English-language 'traditional' ones. This might seem worrying given our concern regarding territorial anchoring of SSPSS offers, but we nevertheless feel that the main generic points of attention have been identified. Another limitation of the literature review regards its scope and exclusion criteria. A potentially rich strand of literature on PSS in computer science, engineering, design and potentially other disciplines were not selected because of their assumed lack of substantive results on real-world PSS cases and overly technical content (regarding the purposes of the article). This in no way means that no relevant insight can be drawn from it, and undoubtedly a more technical discussion of some or all the elements discussed in the text could be a valuable complement to the present research.

At a more substantial level, several remarks are in order. First, we focused on the environmental dimension of sustainability with little attention paid to economic viability and social impacts. This is obviously not because these dimensions are irrelevant,⁹ but we put more emphasis on the reason why (S)PSS are increasingly brought to the fore in circular economy discussions: its potential to dematerialise economic activity. This is also a reflection of the strong sustainability approach developed in the paper, which tends to consider environmental sustainability (at the global level, at least) as a prerequisite for social and economic sustainability. Second, the investigation was limited to use-oriented and performance-oriented PSS, with most of the literature and of the case studies pertaining to the use-oriented category. So, the screening tool.

Another limitation to the research is that potential trade-offs between SSPSS dimensions and criteria have not been systematically assessed. We assume at this stage that there are more synergies than contradictions in the performance of real-world companies across dimensions, but this remains to be verified on a broader empirical basis and with suitable sustainability indicators. What if environmental impacts of a PSS crucially depend on providing maintenance, education and advice to users and at the same time on reducing provider travels to users' homes (Chun and Lee, 2017)? What if heightened incentives to prolong a product's lifetime impair penetration of a new generation of

product with much lower use-phase impacts? Are sufficiency-oriented PSS more likely to develop close links with local stakeholders? Do locally anchored businesses have an easier time providing suitable and efficient access to a fleet of goods? Is territorial anchoring and cooperation always a driver of narrower and slower product loops (see, e.g., Roman et al., 2020)?

These are only a few questions for future research in line with the present paper's contribution. Answering these questions will determine whether SSPSS as defined here constitute a 'model' *per se* with coherent elements. Such research endeavour is probably made difficult by the fact that there are hardly any cases of such SSPSS "ideal-type" in the real world. Indeed, we are not aware of an existing SPSS displaying high performance across all the required dimensions. Many SPSS are developed in an eco-efficiency perspective, with little attention paid to rebound effects and to sufficiency. Many SMEs trying to implement an SPSS are struggling to increase their clients base while keeping their logistics costs (financial and ecological) under control. Some fast-growing start-ups providing access to a fleet of goods may sacrifice systemic performance and/or territorial relevance for the sake of increasing market share. As an illustration, Swapfiets provides bikes as-a-service and has a high potential of becoming an SSPSS, but some problems might remain to be addressed in terms of material flows management before strong sustainability is ensured (Van Tiel, 2019).

Finally, interactions between dimensions raise the need for a more dynamic look at the proposed screening tool. Not all features of SSPSS can or should be developed at the same stage with the same depth. And forms of PSS could evolve from ones attracting consumers to non-ownership offers because they involve lower cognitive barriers (e.g., pay-per-use) to ones likely to be more conducive to strong sustainability but involving deeper acculturation (e.g., performance-related subscription) (see Muylaert et al., 2022).

6. Conclusion

Even though PSS are multiple and many-sided, they are unanimously recognised in the scientific literature as a promising way of increasing circularity and sustainability in business. But the problem is that the case is hard to make that a given PSS unambiguously contributes to sustainability. Moreover, many PSS/access-based offers/functional economy initiatives (however they are labelled and marketised) are developed with little attention paid to the hard challenges of PSS sustainability, so their full potential is only partially (if ever) reaped.

Drawing on both systematic and non-systematic literature reviews and on a deep dive into the reality of PSS development in Brussels (Belgium), the paper identified and illustrated important sustainability challenges. Appraised from a social ecological economics/strong sustainability vantage point, these challenges have been articulated with insights from the sustainable business model literature to devise strong sustainability appraisal guidelines. Reading the scientific literature on sustainability assessments of PSS conveys a general conclusion: the potential of PSS to drive sustainability is dependent on several conditions that are both internal to PSS design and relating to the socio-economic and infrastructural context within which the PSS operates. Building on this general insight, the paper proposed a new characterisation and definition of PSS anchored in strong sustainability and taking stock of the existing knowledge on the sustainability challenges PSS most frequently face: Strongly Sustainable Product-Service System (SSPSS).

Five key dimensions of SSPSS have been identified: access, substitution, systemic dematerialisation, territorial anchorage and sufficiency. We show that to be strongly sustainable, PSS need first to make sure that the supporting product is suitable for non-ownership and access-based use practices. PSS designers should also ensure that the offered product/service will effectively substitute previous damaging practices on a long-term basis. Systemic dematerialisation should be achieved by ensuring that rebound effects and problem-shifting are minimised and by increasing the immaterial content of the offer. How the PSS is

⁹ An introduction to the social dimensions of PSS can be found in Sousa-Zomer and Cauchick Miguel (2018). Barquet et al. (2016) provides a literature review of sustainability factors for PSS that encompasses the 3 'traditional' dimensions of sustainable development (social, economic, environmental).

anchored in a specific geographic and socio-institutional territory is also of great importance to enhance the relevance of the offer and to ground it solidly in cooperation networks. Finally, a sufficiency approach to how the PSS is designed, marketed and connected to customers is a prerequisite to curtail frequent access-based consumption anti-ecological drifts. These dimensions are further refined into criteria (15 in total) and corresponding relevant questions.

Further research could test the grid on real-world cases of PSS development, in order to assess and improve its relevancy and practicality. Other/complementary relevant questions could be identified and adapted to regional/institutional contexts. A relevant addition to the present paper would be identifying synergies and trade-offs between criteria, in order to improve the transformative potential of the framework. This could also be usefully complemented with more dynamic hints into how PSS providers could proceed progressively to improve their offer and get closer to an SSPSS.

Author credits

Philippe Roman: Conceptualisation; Formal analysis; Funding acquisition; Investigation; Methodology; Supervision; Writing - original draft; Writing - review & editing.

Géraldine Thiry: Conceptualisation; Data curation; Formal analysis;

Appendices.

Appendix A. Scopus search key terms

TITLE-ABS-KEY ("Sustainable Product service system" OR "Sustainable Product-service system" OR "Functional economy" OR "Product service system" OR "Product-service system" OR "access-based consumption") AND TITLE ("analysis" OR "Assessment" OR "evaluation" OR "appraisal" OR "impact") AND (SRCTYPE (j)) AND LANGUAGE ("English") AND TITLE-ABS-KEY ("sustainab*" OR "ecolog*" OR "green" OR "environ*") AND (LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA, "SOCT") OR LIMIT-TO (SUBJAREA, "ECON") OR LIMIT-TO (SUBJAREA, "ARTS") OR LIMIT-TO (SUBJAREA, "MATE") OR LIMIT-TO (SUBJAREA, "PSYC") OR LIMIT-TO (SUBJAREA, "MULT")).

Appendix B. Papers selected from the systematic review on PSS sustainability assessment after in-depth reading (n = 26) (English-language literature only)

Author(s)	Title
1 Allais and Gobert (2019)	(IM-)Material flow analysis for system innovation
2 Allais and Gobert (2016)	A multidisciplinary method for sustainability assessment of PSS: Challenges and developments
3 Amasawa et al. (2020)	Environmental potential of reusing, renting, and sharing consumer products: Systematic analysis approach
4 Amaya et al. (2014)	Design for intensified use in product-service systems using life-cycle analysis
5 Blüher et al. (2020)	Systematic literature review-Effects of PSS on sustainability based on use case assessments
6 Chun and Lee (2017)	Environmental impacts of the rental business model compared to the conventional business model: a Korean case of water purifier for home use
7 Costa Junior et al. (2019)	Towards systems-oriented energy solutions: A multilevel analysis of a low-income energy efficiency program in Brazil
8 Devisscher and Mont (2008)	An analysis of a product service system in Bolivia: Coffee in Yungas
9 Firkorn and Müller (2012)	Selling Mobility instead of Cars: New Business Strategies of Automakers and the Impact on Private Vehicle Holding
10 Glatt et al. (2019)	Technical Product-Service Systems: Analysis and reduction of the Cumulative Energy Demand
11 Guyon et al. (2021)	Prioritisation of modelling parameters of a free-floating car sharing system according to their sensitivity to the environmental impacts
12 Allen Hu et al. (2012)	Development of sustainability evaluation model for implementing product service systems
13 Johnson and Plepys (2021)	Product-service systems and sustainability: Analysing the environmental impacts of rental clothing
14 Kjaer et al. (2018)	Guidelines for evaluating the environmental performance of Product/Service-Systems through life cycle assessment
15 Kjaer et al. (2016)	Challenges when evaluating Product/Service-Systems through Life Cycle Assessment
16 Liu et al. (2020)	How sustainable is smart PSS? An integrated evaluation approach based on rough BWM and TODIM
17 Muñoz López et al. (2020)	Sustainability assessment of product-service systems using flows between systems approach
18 Martin et al. (2021)	Environmental assessment of a product-service system for renting electric-powered tools
19 Mont (2004)	Reducing life-cycle environmental impacts through systems of joint use
20 Rosa et al. (2019)	Circular Business Models versus circular benefits: An assessment in the waste from Electrical and Electronic Equipments sector
21 Scheepens et al. (2016)	Two life cycle assessment (LCA) based methods to analyse and design complex (regional) circular economy systems. Case: Making water tourism more sustainable
22 Sousa-Zomer and Cauchick Miguel (2018)	The main challenges for social life cycle assessment (SLCA) to support the social impacts analysis of product-service systems
23 Suckling and Lee (2015)	Redefining scope: the true environmental impact of smartphones?
24 Van der Veen et al. (2017)	Exploring policy impacts for servicing in product-based markets: A generic agent-based model
25 Van Loon et al. (2021)	Circular products and business models and environmental impact reductions: Current knowledge and knowledge gaps
26 Wasserbaur et al. (2020)	What if everyone becomes a sharer? A quantification of the environmental impact of access-based consumption for household laundry activities

Source: Authors

Funding acquisition; Methodology; Project administration; Supervision; Writing - original draft; Writing - review & editing.

Coralie Muylaert: Conceptualisation; Investigation; Methodology; Writing - original draft.

Coline Ruwet: Conceptualisation; Funding acquisition; Methodology; Supervision; Writing - original draft; Writing - review & editing.

Kevin Maréchal: Conceptualisation; Funding acquisition; Methodology; Supervision; Writing - original draft; Writing - review & editing.

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

Interview data are confidential.

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Appendix C. Papers selected from the integrative review on PSS sustainability assessment after in-depth reading (n = 14) (English-language literature only)

	Author(s)	Title
1	Agrawal et al. (2012)	Is Leasing Greener Than Selling?
2	Barquet et al. (2016)	Sustainability Factors for PSS Business Models
3	Bech et al. (2019)	Evaluating the Environmental Performance of a Product/Service-System Business Model for Merino Wool Next-to-Skin Garments: The Case of Armadillo Merino®
4	Besch (2005)	Product-service systems for office furniture: Barriers and opportunities on the European market
5	Castro et al. (2022)	The rebound effect of circular economy: Definitions, mechanisms and a research agenda
6	Doualle et al. (2015)	Investigating Sustainability Assessment Methods of Product-service Systems
7	Hoffmann et al. (2020)	Life cycle assessment of innovative circular business models for modern cloth diapers
8	Kerdlap et al. (2021)	To Rent or Not to Rent: A Question of Circular Prams from a Life Cycle Perspective
9	Khumboon et al. (2009)	Environmental impacts of rental service with reconditioning – a case study
10	Kjaer et al. (2019)	Product/service-systems for a circular economy: The route to decoupling economic growth from resource consumption?
11	Lindahl et al. (2014)	Environmental and economic benefits of Integrated Product Service Offerings quantified with real business cases
12	Matschewsky (2019)	Unintended Circularity?—Assessing a Product-Service System for its Potential Contribution to a Circular Economy
13	Tasaki et al. (2006)	A quantitative method to evaluate the level of material use in lease/reuse systems of electrical and electronic equipment
14	Zamani et al. (2017)	Life cycle assessment of clothing libraries: Can collaborative consumption reduce the environmental impact of fast fashion?

Source: Authors

Appendix D. Papers selected from the integrative review on PSS sustainability assessment after in-depth reading (n = 10) (French-language literature only)

	Author(s)	Title (in French)
1	ADEME et al. (2017)	Vers une économie de la fonctionnalité à haute valeur environnementale et sociale en 2050. Les dynamiques servicielle et territoriale au coeur du nouveau modèle.
2	Bourg and Buclet (2005)	L'économie de fonctionnalité. Changer la consommation dans le sens du développement durable.
3	Buclet (2014)	L'économie de fonctionnalité entre éco-conception et territoire: une typologie.
4	Du Tertre (2013)	Économie servicielle et travail: contribution théorique au développement "d'une économie de la coopération"
5	Gaglio et al. (2011)	L'économie de la fonctionnalité: une voie nouvelle vers un développement durable
6	Keucheyan (2019)	Les besoins artificiels. Comment sortir du consumérisme.
7	Pereira and Vence (2020)	Les systèmes produit-service comme business models pour l'économie circulaire: potentialités et limites.
8	Roman et al. (2020)	Intégrer la territorialité pour une économie de la fonctionnalité plus soutenable.
9	Serra (2018)	Perspectives durables et territoriales des économies de fonctionnalité légitimes. Une interprétation en termes conventionnalistes.
10	Sidoli (2017)	L'usage en partage: Analyse comparative des modèles socio-économiques d'"économie de (la)fonctionnalité" et d'"économie collaborative"

Appendix E. Details on organisations interviewed

Interviews covered a total of 9 distinct organisations providing SPSS in 7 distinct sectors (clothing - 2, tooling, household appliances, reusable deposits, cycling, furniture, miscellaneous low use frequency objects) and one public library. Concerning the latter, it is not strictly speaking an SPSS but certainly a type of organisation performing SPSS-like activities from which relevant insights can be drawn.

- The clothing cases refer to two clothing libraries: the first one for pregnant women and babies, offering its service upon subscription, and the second one for women, offering evening dresses rental service on a pay-per-use basis.
- The tooling case concerns a not-for-profit tooling library offering quality tools with personalised advice and practice space in its premises.
- The household appliance case is about B2C rental of coffee machines upon subscription.
- The reusable deposits case relates to recovery and reuse of glass jars on a deposit basis.
- The cycling case regards long-term rental of bicycles for children upon subscription with possibility to swap bicycles as children grow.
- The furniture case deals with the supply of modular wooden structures that can be used for a variety of purposes (theatre sets, stand-up tables, office layouts, temporary structures for events, etc.) with the possibility for the company to take the structures back after use and for users to repurpose them.
- The objects library case is about pay-per-use rental of low-frequency-of-use objects of all kinds. Finally, the studied public library offers a range of services revolving around reading activities (book rental, reading clubs, storytelling ...).

Appendix F. Full-length SSPSS screening tool

Dimension of SSPSS	Criteria	Relevant questions
Access	Non-ownership	➤ Is it suitable and convenient to provide access to the product?
	Functions	➤ What are the challenges of renting/leasing/sharing this good?
		➤ What are the functions performed by the offer?
		➤ What (basic) needs does it meet?
Substitution	System displacement	➤ Does the PSS enrich the offer beyond the (material) product?
		➤ Can the transport challenges of providing physical access to the product be accommodated in a viable way?
		➤ Is the PSS a substitute for the sale of a less environmentally efficient material product?

(continued on next page)

(continued)

Dimension of SSPS	Criteria	Relevant questions
Systemic dematerialisation	Quantity reduction via long lifetime products	➤ How long is the product expected to last and to stand as a substitute for other consumption?
	Degree of materiality of the offer	➤ How material is the PSS? ➤ What are its material and energetic requirements?
	Circularity and lifecycle reasoning	➤ Does the organisation manufacture and/or is supplied with eco-conceived products? ➤ Does the organisation promote resource-savvy use of its products? ➤ How far is the organisation committed to managing the least impactful possible end of life of the goods?
	Impacts of logistics	➤ Are the production cycles of the goods short? ➤ Do consumers make long and frequent journeys to access the goods?
	Immaterial practices	➤ Is the whole life cycle of the product designed to use energy efficient devices? ➤ What is the share of immaterial practices (human relationships, services etc.) that come with PSS delivery? ➤ Does the PSS require social/community involvement? ➤ Does the organisation promote human relationships that substitute for consumption-based needs fulfilment?
Territorial anchoring and cooperation	Upstream/downstream cooperation	➤ What is the depth and breadth of cooperation with stakeholders in the supply and value chains?
	Internalisation of a large range of externalities	➤ To what extent does enlarged cooperation allow to shoot many targets with the same stone?
	Territorial grounding	➤ What is the depth and quality of integration into the local economic and social fabric? ➤ What is the quality of cooperation with local institutions and government?
Sufficiency	Impact on consumer and provider culture	➤ Are the offer and its marketisation conducive to questioning demand and challenging the quantity of consumption?
	Promotion of immaterial practices	➤ Does the PSS provide access to goods in a way that promotes interpersonal contact and socialising opportunities?
	High quality prescription	➤ Does the PSS overcome 'consumer sovereignty' to convince clients that getting access to high-quality products is the right thing to do, and it is worth the price?

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