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Sustainable servitization for cleaner and resource-wise production and consumption: Past, present, and future

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Sustainable servitization for cleaner and resource-wise production and consumption: Past, present, and future

1. Introduction

In the late 1990s, product-service systems (PSS) emerged from integrating products and services to meet customer needs (Goedkoop et al., 1999). Over time, the literature evolved into recognizing that PSS, compared to traditional offerings, could be sustainable solutions that create environmental, societal, and economic value (Mont, 2002; Roy, 2000; Tukker and Tischner, 2006). Starting from ideas such as dematerialization, researchers proposed new business logic based on selling functionality rather than goods (Alonso-Rasgado et al., 2004; Dobers and Wolff, 1999). These logics often involved eco-design, cleaner production, efficient delivery, and remanufacturing (Rabetino et al., 2018). Notably, the emergence of the Sustainable PSS (SPSS) concept echoed a move in sustainability-related research (Manzini et al., 2001; Roy, 2000). A new scholarly community focused on how SPSS can result in lower environmental impact, greater social responsibility, and additional social benefits (Hernandez, 2019; Mont, 2002).

Initially, the literature embraced a technical approach while also stressing the importance of SPSS design-related processes and practices, exploring the configuration of SPSS in the B2C and B2B contexts and examining the effect of eco-efficiency on economic growth, SPSS assessment from an environmental perspective, and SPSS implementation and business model innovation (Chou et al., 2015; Durugbo, 2013; Vezzoli et al., 2015). Studies also focus on the implications of sustainable production and consumption policy and social impacts. The SPSS concept became a suitable opportunity for rethinking the role of services as a means of cleaner and sustainable industrialization (Annarelli et al., 2016; Ceschin, 2013; Sousa and Cauchick Miguel, 2015). Indeed, the most sustainable PSS were described as those aiming at selling functionality based on servicing and use-or result-oriented business models (Kühl et al., 2018; Tukker, 2015; Tukker and Tischner, 2006). Still, SPSS has also been demonstrated to be a difficult-to-implement model, with the design-related and operational aspects of SPSS being the most significant obstacles (Hernandez, 2019; Reim et al., 2017).

Lately, the Circular Economy (CE) paradigm has gained consideration as an avenue to resolve sustainability grand challenges (Liu et al., 2024), whereas the implementation of SPSS has been pointed as a strategy to enhance business circularity (Bocken et al., 2017; da Costa Fernandes et al., 2020; Kjaer et al., 2019). However, researchers acknowledged that not all PSS deliver sustainable solutions (Tukker, 2015; Zeeuw van Der Laan and Aurisicchio, 2019). In other words, not all PSS are SPSS. Some studies also argued that PSS do not necessarily lead to higher circularity (Pieroni et al., 2019; Tukker, 2015; Zink and Geyer, 2017). Indeed, the potential contributions of PSS to achieve product re-usage and component circularity have not been studied (Blomsma et al., 2018; da Costa Fernandes et al., 2020). Moreover, the focus on sustainability has somehow decreased during the evolution of PSS research. For instance, Haase et al. (2017) found that many of the 52 definitions of PSS they analyzed do not refer to the environmental impact of PSS, and the presence of these references has decreased over time, which represents a refocus from ecological to economic benefits (Kjaer et al., 2019), creating two diverging streams: 1) PSS's environmental agenda and 2) PSS's design and development (Rabetino et al., 2018).

Simultaneously, servitization scholars studied the transition from selling products and services to selling PSS in an adjacent research community, which calls for business model innovation to integrate advanced life-cycle services into complex PSS offerings (Rabetino et al., 2018, 2015). Thus, the servitization research has explored the benefits of servicizing and product-service integration in manufacturing from a management-oriented view (Baines et al., 2007; Rothenberg, 2007). Scholars used labels for the most sustainable business models, such as integrated solutions, advanced services, and performance- or outcome-based contracts (Rabetino et al., 2018). The debate was somehow rooted in the early PSS literature and acknowledged relevant aspects such as the concept of life-cycle services and alternative routes to sustainable offerings in many sectors (Naor et al., 2018; Pelli and Lähtinen, 2020; Rabetino et al., 2015). Still, the focus on sustainability has not initially been at the core of the recent servitization debates. Moreover, Rabetino, Kohtamäki, Brax, and Sihvonen (2021) found that understanding capabilities for after-sale life-cycle services was a 'cooling topic' in servitization research, although sustainable servitization was germinating as an emerging stream (Opazo-Basáez et al., 2018).

In any case, the accumulated knowledge is vast after three decades of research, and the trend seems to be reversing in the servitization literature, albeit still based on isolated and somehow uncoordinated actions. Different scholars showed how service innovation and servitization might offer a solid basis for decarbonization towards net-zero emissions by combining business and technical approaches. Notwithstanding some remarkable exceptions (Coreynen et al., 2021; Marić and Opazo-Basáez, 2019; Opazo-Basáez et al., 2018), the full benefits of sustainability- and circularity-oriented servitization are not entirely studied. Moreover, although there has been a proliferation of publications on the link between PSS and CE over the past five years (da Costa Fernandes et al., 2020; Kjaer et al., 2019; Kühl et al., 2019), there is no commonly agreed conclusion or a complete understanding of how the use of PSS contributes to circularity (Blomsma et al., 2018; da Costa Fernandes et al., 2020; Matschewsky, 2019). The time seems to have come when the PSS and servitization communities should make a joint effort (Rabetino et al., 2021b) and discuss the link between product-service integration and sustainability. Indeed, there are multiple opportunities to extend servitization research in this direction (Reim et al., 2015). The goal is to understand how research can address and respond to the planet's trends and look for broader societal impact (Abdelkafi, Nizar et al., 2022).

Against the above backdrop, the aim of this paper is threefold. First, this study examines the antecedents of the sustainable servitization concept, which includes but goes beyond the original idea of SPSS by considering the resulting offerings and business models and the related transition process. Drawing on this growing literature, we discuss the prevailing key themes and conceptions and discover the differences between rationalizations in theoretical and empirical documents. Second, the paper introduces the articles in this Special Issue, for which our call invited multidisciplinary conceptual and empirical contributions concerning (digital) servitization in supporting sustainability, circularity, green/sustainable supply chain, and resource wisdom in manufacturing. Finally, we highlight future research directions and indications for developing the field.

2. The role of servitization and PSS in fostering sustainability and circularity

Previous research covers various interrelated topics concerning the role of servitization and PSS in fostering sustainability and circularity. For instance, studies examine the impact of servitization on sustainability (Kohtamäki et al., 2024) and circularity through business model innovation (Parida et al., 2019; Reim et al., 2015; Spring and Araujo, 2017). Other articles in neighboring topical areas deal with digitalization and servitization for sustainable manufacturing and green supply chain management (Ren et al., 2019; Schiavone et al., 2022; Sjödin et al., 2023). Papers also focus on value creation, business model innovation, circular supply chain, and operations management, and the role of technological innovation and digitalization (Bressanelli et al., 2018a; Guzzo et al., 2019; Pieroni et al., 2019). Other topics related to PSS implementation are cited in the PSS literature (Kjaer et al., 2019; Yang et al., 2018). Examples include assessing circular and sustainable PSS (De Los Rios and Charnley, 2017; Sousa-Zomer and Miguel, 2017). Additionally, research has focused on understanding the design and industrialization of SPSS (Ceschin, 2013; Evans et al., 2007; Manzini and Vezzoli, 2003). Finally, the consumption side of SPSS, involving business practices, user interventions, and customer acceptance, has also captured scholars' attention (Catulli et al., 2017; Retamal, 2017).

While SPSS is a consolidated concept (Ceschin, 2013; Evans et al., 2007; Manzini and Vezzoli, 2003), sustainable servitization has no clear definition. Articles use partially overlapping concepts such as green servitization (Opazo-Basáez et al., 2018) or sustainable servitization (González Chávez et al., 2021; Kohtamäki et al., 2024). These circumstances may harm knowledge accumulation, mainly due to setting barriers to constructing common meanings and vocabularies (Rabetino et al., 2021a), which calls for the future homogenization of labeling. Moving toward such a goal, a closer examination of the existing research allows us to understand the nuances and overlaps in the knowledge accumulated in the last thirty years.

2.1. Servitization and sustainability

Existing research covers a broad spectrum concerning the link between servitization and sustainability, from a clear link to a non-existing relationship and many contingent positions. For instance, Opazo-Basáez et al. (2018) claim that green servitization enhances sustainability by optimizing resource utilization. Studies also suggest that servitization improves energy consumption (Doni et al., 2019) and efficiency or promotes energy conservation and emission reduction (Marić & Opazo-Basáez, 2019), therefore enhancing environmental performance and contributing to sustainability in supply chains (González Chávez et al., 2024; Paschou et al., 2020). Moreover, servitization was found to influence product lifespan and end-of-life recovery positively (Vendrell-Herrero et al., 2022), enabling flexible and sustainable supply chain management (Marić and Opazo-Basáez, 2019) and fostering services and business models innovation (Han et al., 2020; Paiola et al., 2021) and collaboration in networks in B2C (Kreye and van Donk, 2021). Servitization also may promote a shift from a linear to a circular economy (Bressanelli et al., 2020; Han et al., 2020;

Hidalgo-Carvajal et al., 2021) by increasing supply chain circularity (Mishra et al., 2023) through increased product longevity, closure of resource loops and resource efficiency, easier transition to new manufacturing processes, usage, and disposal patterns (Kühl et al., 2019).

However, servitization may not always implicate sustainability or circularity (Doni et al., 2019; Spring and Araujo, 2017). Indeed, the link may be, at best, questionable (de Jesus Pacheco et al., 2019; Roman et al., 2023). Several studies suggest that the sustainability-related benefits of servitization are contingent. For instance, Kanatlı and Karaer (2022) conclude that, while servitization's environmental benefits are contingent and depend on product-related costs, customer diversity, and market composition, the environmental advantages do not always align with firms' economic incentives. While cautioning about the sustainable servitization paradox in the context of manufacturing companies, Kohtamäki, Bhandari, Rabetino, and Ranta (2024) found a negative direct relationship between manufacturing firms' sustainability emphasis and firm profitability but also a positive moderating effect of servitization on the relationship between manufacturing firms' sustainability emphasis and company profitability.

Also, taking a contingent perspective, Abdelkafi et al. (2022) propose that the connection between servitization and sustainability depends on whether the newly designed PSS extends the product lifecycle. They claim that a systemic view is needed to unlock the latent sustainability potential of servitization and achieve an entirely positive impact on the environment, which involves being able to track products throughout the entire life cycle until the end of life. Manufacturers require supplementary financial incentives to embrace sustainability-related initiatives amid the transformation of the business model driven by servitization. In another study, Lafuente and Vaillant (2023) conclude that combining servitization and a green strategy leads to higher competitive efficiency than pursuing none or only one strategy. Finally, Zhang, Qi, Wang, and Lyu (2022) suggest that servitization enhances environmental performance only in the presence of high levels of absorptive capacity and human resource slack.

Sometimes, but not always, sustainable and circular servitization may go hand in hand with or are enabled by digitalization (González Chávez et al., 2024; Opazo-Basáez et al., 2018; Sjödin et al., 2023). Thus, digital servitization (Kohtamäki et al., 2022) may be a vehicle towards sustainable manufacturing. Paschou, Rapaccini, Adrodegari, and Saccani (2020) conceptually argue that digital servitization has several benefits, such as reducing energy consumption and increasing the sustainability of production processes via efficiency gains, results also acknowledged by empirical studies (e.g., González Chávez et al., 2024). Moreover, González Chávez et al. (2024) conclude that promoting shared costs and responsibilities in digital servitization can contribute to sustainability by equitably redistributing benefits throughout the value chain. Additionally, Paiola et al. (2021) conclude that digital services promote customers' sustainability gains linked to shifting products to customers' processes and leveraging transformations in network relationships in ecosystems of any size. Indeed, digital technology enables more efficient and cleaner production. For instance, the digital component may further enhance the sustainability-related benefits of servitization. In this context, Schiavone, Leone, Caporuscio, and Lan (2022) propose that Industry 4.0, specifically technologies such as additive manufacturing and 3D printing, significantly impacts supply chains and offers environmental benefits in manufacturing processes.

Literature also explores the role of digital technologies in CE (Nobre and Tavares, 2017). For instance, studies analyze the role of sensors and IoT in monitoring obsolescence and supporting closed loops (Pagoropoulos et al., 2017; Zeeuw van Der Laan and Aurisicchio, 2019). Moreover, IoT technology supports product design and material tracking and helps to close the loop (Bressanelli et al., 2018a). Sensors and ERP systems were also found to support decision-making processes and improve sustainability indicators (González Chávez et al., 2019a). Particularly, Bressanelli et al. (2018a) examine the role of IoT, analytics, and Big Data as enablers of CE through different functionalities (e.g., product design, customer attraction, and product usage optimization, monitoring product activity, providing technical-, maintenance-, and upgrading-related services, and managing EoL activities). They discuss how these functionalities may increase resource efficiency, extend product lifespan, and help to close the loop. In the analyzed use-oriented model, most of the functionalities come into play during the usage phase of the product (middle of the product life, MoL), but they are not related to closing the loop. Consequently, much effort must be placed in the design phase or at the EoL through reverse logistics (Bressanelli et al., 2018a).

2.2. PSS and sustainability

Servitization means transitioning from selling products and basic services to selling PSS and potentially involves different strategies that materialize in alternative PSS-based business models (Kohtamäki et al., 2019; Rabetino et al., 2018). As a result of servitization strategies, PSS can potentially contribute to sustainability and circularity. Indeed, academics often assume that almost all PSS somehow lead to sustainability (directly or indirectly). However, existing research also suggests that PSS are not always sustainable PSS (Hernandez, 2019; Tukker, 2015; Zeeuw van Der Laan and Aurisicchio, 2019). Of course, use- and result-oriented PSS facilitate dematerialization of consumption by selling functionality and results rather than products when product suppliers retain ownership. Previous studies highlight that PSS offerings are still typically built on renting, leasing, or sharing, with the addition of product-related services aiming at extending the product lifespan. Consequently, while products still have a central role in the dominant narratives, PSS-enabled business models may contribute to sustainability by altering a company's strategic focus from commoditized products to selling complex integrated solutions involving advanced services, which lead to resource efficiency, decoupling economic growth from resource consumption and reducing environmental impact (Vezzoli et al., 2015).

Concerning the effects of PSS on circularity, the most attention is on a traditional set of topics, such as closed loops and the supply chain (and ecosystems), circular product or eco-efficient design, and circular business models. As for the effects of PSS on circularity, Pieroni et al. (2019) suggest that the PSSs with the most significant potential to contribute to circularity are characterized by being niche or 'one-of-its-kind' solutions that are configured for certain types of products and market segments or geographical areas and "represent a large revenue volume", such as Rolls Royce's Power-by-the-hour. The total contribution of PSS to a CE will depend on both efficiency (reducing resource use and flows) and effectiveness (retaining the value of resources and maximizing systemic economic and ecological benefits) in the provision of PSS (Matschewsky, 2019; Pieroni et al., 2018). Kjaer, Pigosso, McAloone, and Birkved (2018) clarify the characteristics that the PSS must meet to be circular, whereas other scholars focus on analyzing the specific set of activities that foster the contribution of PSS to resource reduction towards a CE and the assessment of these activities (Kjaer et al., 2019; Matschewsky, 2019).

Accordingly, by transforming linear models into circular models that maximize economic benefits and reduce environmental impact (Guzzo et al., 2019), PSS may reduce the flow of resources and the generation of waste, which facilitates resource decoupling and slower and closed resource loops. Yang et al. (2018) propose that product-, use-, and result-oriented PSS may potentially affect the supply chain circularity and create value. Kühl et al. (2018) suggest that offering PSS based on selling functionality incentivizes manufacturers to include CE elements in their operations. Based on manufacturers retaining product ownership and a pay-for-asset functionality revenue model, SPSS are well suited to the requirements of a circular economy (Hernandez, 2019; Tukker, 2013). In particular, these SPSS are built from use- and result-oriented business models (Yang et al., 2018).

Yang et al. (2018) and Kühl et al. (2019) concur that the impact on circularity increases when moving from product- to use- and result-oriented PSS. According to Yang et al. (2018), product- and use-oriented PSS create value by minimizing material usage and other cost reduction based on reuse, refurbishing, and recycling, as well as prolonging product longevity and maximizing the number of cycles being the impact of use-oriented PSS on circularity higher in both cases. Result-oriented PSS also create value by adopting a symbiosis approach (co-products and by-products). When moving from product- to result-oriented models, enlarged product longevity seems to be the primary dimension that explains the increasing marginal upturns in circularity, followed by additions related to more closed loops and increased resource efficiency (Kühl et al., 2019).

The existing research addressed various circular strategies. Starting from existing empirical studies in a variety of industries (e.g., home water purifiers, household equipment, and mobile phones), Blomsma et al. (2018) frame the benefits of PSS towards a CE as related to the potential simultaneous use of different circular strategies such as reuse, remanufacturing, recycling, and product maintenance. Thus, resource loops can be closed by extending the products' lifetime based on repairs and maintenance or through remanufacturing/reusing and recycling (Kühl et al., 2019). Extending products' life through maintenance and upgrading, and revalorizing them through reuse or remanufacturing are among the available CE-related practices, which result in slower and more closed resource loops that reduce the resource consumption and increase resource efficiency over the product life-cycle (Kühl et al., 2018). Because second-hand products do not always replace first-hand products, "… to ensure a net resource reduction, CE strategies based on reuse and recycling should confirm that actual "displacement" takes place" (Kjaer et al., 2019).

Different typologies, classifications, or frameworks are also available to systematize the understanding of strategies and practices. For instance, Widmer et al. (2018) discuss five hierarchical recovery strategies for servitized products that, when applied throughout the life-cycle, might end up closing the supply chain loop: 1) maintain, clean, refill, 2) repair, refurbish, upgrade, reuse, 3) remanufacturing and part harvesting, 4) material recycling, and 5) scrap and energy recovery. Kjaer et al. (2019) identify five PSS strategies: 1) product maintenance, 2) operational support, 3) optimized results, 4) product sharing, and 5) tale-back/End-of-life (EoL) management. The combination of the above strategies supports four enablers of relative resource reduction. Thus, operational support and product maintenance can result in *operational efficiency* (in all types of PSS), which reduces the need for resources during product use throughout its life cycle (e.g., fuel, energy, or materials). Product maintenance and the EoL management (and take-back) strategies increase *product longevity* (in all types of PSS) and, along with an *intensified usage of sub-utilized products*, displace individual ownership and exploit unutilized capacity (for instance, through product sharing or renting) while reducing the need for producing the product via an increment in product utility. Finally, strategies based on EoL management, product sharing, and performance optimization can result in *product system substitutions* (shifting how users' needs are fulfilled) and displace more resource-intensive systems (Kjaer et al., 2019).

PSS's role in configuring novel circular business models that allow resource decoupling and supply chain circularity is central (Pieroni et al., 2019; Reim et al., 2015; Yang et al., 2018). To understand how PSS contribute to circularity in practice, it is critical to configure business models that simultaneously allow the extension of the lifespan of products and components and the closing of material loops. According to Pieroni et al. (2019), in practice, this configuration means not only designing circular business models but also assessing their potential for delivering superior customer value (e.g., market potential and increasing customer surplus), economic growth (e.g., positive net profit, available investment requirements, and favorable upscaling conditions), and resource decoupling (e.g., positive net resource reduction, mitigate rebound effects, absent burden shifting between life cycle stages). Recent frameworks include practices and tools to facilitate decision-making and support the transition towards circular business models through business model innovation. For instance, Guzzo et al. (2019) identify practices for operationalizing four circular strategies. Thus, practices were classified into practices to enhance resource-effectiveness in the inner circle, for circling longer, through cascade use and pure inputs. These authors found that product-oriented PSS rely on circling longer practices, and all user- and result-oriented PSS rely on at least one of the inner circle practices. The inclusion of cascade use practices is not extended.

When considering the essential practices, design undoubtedly plays a central role (González Chávez et al., 2019; Matschewsky, 2019), and design-related practices are the most acknowledged in existing research. Although design is performed at the beginning of life (BoL), it must adopt an entire life cycle (LC) approach to increase circularity. Among many characteristics, articles highlight the need to consider design for servicing (Kjaer et al., 2019; Rabetino et al., 2015), recycling and remanufacturing (Bressanelli et al., 2018b; Yang et al., 2018), closing the loop (Bressanelli et al., 2018a; Zeeuw van Der Laan and Aurisicchio, 2019), and revalorization (Zeeuw van Der Laan and Aurisicchio, 2019). For instance, closed loops can be designed based on obsolescence planning, monitoring, and management, including the option of offering gateways such as take-back schemes and the valuation of obsoletes to create demand and transfer them to the following life-cycle phases (Zeeuw van Der Laan and Aurisicchio, 2019). Overall, while collaborative design and early customer involvement seem critical when designing circular and lean PSS (González Chávez et al., 2019b), studies may need to focus more on understanding the trade-off between all the existing 'design for' options.

Many challenges can also be listed when considering circular PSS (Linder and Williander, 2017). Thus, although PSS can potentially support the transition to a CE, circularity is not a necessary outcome (Pieroni et al., 2019; Tukker, 2015; Zink and Geyer, 2017) because the implementation of these business models is often product-centric (Matschewsky, 2019) and driven by profitmaking (Kjaer et al., 2019), and there exist different rebound effects (da Costa Fernandes et al., 2020). PSS may also have hidden costs that must be acknowledged when moving from relative to absolute resource decoupling (ARD), which means a decline in resource use independent of the economic growth rate and is necessary for achieving a genuine reduction in resource consumption. The life-cycle approach and (life-cycle) assessment of the sustainability and circularity of PSS (Kjaer et al., 2018; Michelini et al., 2017; Scheepens et al., 2015) are vital to fulfilling the requirements for ARD. In short, ARD can be achieved through ensuring "net resource reduction" (difference in the amount of all resources avoided and all resources incurred when offering the PSS), avoiding "burden shifting between life cycle stages", and mitigating "rebound effects" (Kjaer et al., 2019). Eco-design can support net resource reduction by diminishing the induced resources and avoiding the burden of shifting between stages by considering the link of resource consumption. Another important aspect is to assess the rebound effects (Tukker, 2013; Zink and Geyer, 2017) of SPSS-based business models and the potential impact on circularity (da Costa Fernandes et al., 2020; Matschewsky, 2019). Kjaer et al. (2019) provide many examples of the main rebound effects concerning PSS, concluding that sometimes PSS providers cannot mitigate them since the causes are out of the providing companies' control.

Also, circular PSS models may suffer from the retained ownership paradox. Kühl et al. (2019) conclude that the observed increment in the quantity and variety of circular practices as business models move from product- to results-oriented is mainly explicated by the retention of product ownership, which sets new incentives because it implies an increment in the providers' responsibility through the entire product life-cycle (Matschewsky, 2019). Product ownership allows for greater control and provides more product flow and behavior information. However, it also leads to greater product reliability and maintainability because manufacturers also look to maximize profits throughout the product life cycle as a price for internalizing operational risks (Kühl et al., 2019). Ownership retention may also motivate manufacturers to extend the product's lifespan while increasing practices such as remanufacturing and reuse (Michelini et al., 2017; Yang et al., 2018). Thus, retained ownership is a necessary condition at the core of the increment of circularity, but, at the same time, retained ownership was found to be a reason to increase the impact of failure (Linder and Williander, 2017), and it may also prevent customers' acceptance of the circular PSS.

Indeed, the potential value for different stakeholders must be assessed to understand the value of a PSS, which includes the evaluation of the trade-off between tangible (transactional) and intangible (e.g., subjective and experiential) benefits and sacrifices (risk and negative impact) at different levels (supply chain and ecosystem) and stages of the life-cycle (Widmer et al., 2018). Customers, consumers, and users are crucial in closing the resource loops, especially when analyzing consumer goods (Zeeuw van der Laan and Aurisicchio, 2019). Studies point out use- and result-oriented PSS as having the greatest potential for circularity, often involving shared product ownership. Yet, product ownership may embody intangible value to those consumers concerned with control, self-identity, intimacy, and hygiene (Camilleri, 2019; Tukker, 2013). Not every customer may also be willing to pay a premium for environmentally superior PSS (Pieroni et al., 2019). The existence of market potential, i.e., enough customers willing to accept and pay for the particular offering (Yang et al., 2018), is a crucial determinant of the total impact of PSS models towards a CE.

Consequently, ownership and customers' acceptance of use- and result-oriented PSS models can be understood as an antecedent of customer value and call for different types of customer-provider interaction based on various strategic orientations of customer experience creation (Schallehn et al., 2019). Existing research suggests that public acceptance is crucial and may become a barrier when implementing PSS business models, although existing evidence mainly comes from use-oriented PSS. Based on a literature review, Camacho-Otero et al. (2018) found that factors affecting consumers' acceptance fall into significant themes, such as personal characteristics and other psychological factors, experience and social aspects, knowledge and understanding, risk and uncertainty, offering and benefits. Regarding the provision of pay-per-use services (Cherry and Pidgeon, 2018) conclude that careful consideration must be given to some specific institutionalized habits and values influencing cultural understanding, such as a desire for ownership (especially in personal items), responsibility (and financial risk), and trust. While payment structures influenced consumer intention to participate in circular business models (Elzinga et al., 2020), infusing meaning and fulfilling intangible needs were found to increase acceptance (Tunn et al., 2019). Customization (Tunn et al., 2019) and information and communication technology enable the customer experience of use-oriented PSS (Schallehn et al., 2019). However, Camacho-Otero et al. (2018) conclude that only a few articles integrate consumers' perspectives into design processes. Finally, previous research also concludes that although policy and practices have advanced, the legislation still lags in many places (Pieroni et al., 2019).

3. The papers in the Special Issue

Since the call for contributions, the Special Issue aimed to discuss the interplay between PSS/servitization and sustainability and boost sustainable servitization-related research. Therefore, we invited multidisciplinary conceptual and empirical contributions concerning the role of these research streams in supporting sustainability, circularity, and resource wisdom, with a particular emphasis on manufacturing. The aim was to discuss the interplay between institutional influences, ecosystem dynamics, and strategic and innovation practices. We were particularly interested in business model innovation towards sustainable servitization and how to achieve sustainability and circularity through PSS and digitally-enabled life-cycle product-service offerings. We searched for submissions from various perspectives with solid conceptual grounding and original and advanced thinking on sustainable and circular servitization to understand how embedding sustainability into business models through PSS and (digital) servitization impacts organizational and ecosystem-wide practices that enable value creation and capture in manufacturing. Earlier versions of these contributions were presented at the International Conference on Business Servitization (www.servitization.org), providing an excellent opportunity for direct interaction between authors and guest editors.

After a productive and stimulating intellectual journey, with fruitful interactions between authors, reviewers, and guest editors, we have put together a collection of articles that we hope will contribute to the construction of the research stream related to sustainable servitization. As might be expected in an academic field searching for definitions and structure, many articles are conceptual or literature reviews from various angles and complement our general review above. However, several empirical articles are also included in this SI. Next, Table 1 presents each paper, starting from the conceptual and review articles.

Table 1 The papers in the special issue.

Article	Type	Contribution to the literature	Areas for future research
Spadafora and Rapaccini (2024). Bridging the gap between servitization and social innovation.	Review	The paper scrutinizes the social implications of servitization, focusing on the connections between servitization and three core views of social innovation. First, the processual view examines the dynamics of social changes. Second, the instrumental view examines mechanisms and tools that drive social changes. Third, the outcomes view addresses the resulting benefits. The paper inductively derives three propositions from arguing that servitization can be considered a form of social innovation with the power to reshape societies and increase well-being. Finally, the paper suggests a set of research priorities and opportunities for further debate.	More research is needed on the social implications and potential social benefits of servitization, which should be considered from the early PSS design stages, including understanding the role of servitization in modifying consumption habits and promoting sustainable consumption.
Stabler, Hakala, Huikkola, and Mention (2024). Aligning Servitization and Circularity: The Role of Institutional Confluence in Sustainable Business Models.	Conceptual	The article explores the alignment between servitization and circular principles driven by the concept of institutional confluence. In doing so, the paper delineates the mechanisms promoting the integration of servitization and circularity, addressing how institutional forces facilitate or hinder such integration by driving the selection of emerging business models and reshaping processes and resources.	Additional empirical research on the roles of institutional confluence and validation of the model in different contexts and industries are needed.
Menon et al. (2024). Unpacking the triple Nexus: Environmental performance, economic performance, and servitization – A systematic review and theoretical reflections.	Review	The review identifies performance measures and contextual variables acting as mediators and moderators, defines the impact of servitization on environmental sustainability and economic performance, and understands how servitization could help balance them in the manufacturing industry. The paper also identifies the theoretical perspectives used to explain servitization's impact through thematic analysis and provides concrete propositions for further research. Moreover, the authors offer different opportunities for managers and policymakers to improve performance from servitization.	It is also necessary to identify alternative variables that may moderate or mediate the link between servitization and environmental and economic performance, analyzing their potential managerial and policy implications. More precise and sophisticated measurements and alternative specific conceptual approaches are also needed and must be developed.
Zhou, Yu, Adams, Attah-Boakye, and Johansson (2024). The impacts and outcomes of sustainable servitisation: A systematic literature review.	Review	The paper examines how sustainable servitization is implemented from the organizational change viewpoint, including a dynamic and processual view and a holistic framework (including antecedents, mechanisms, and outcomes) to comprehend the organizational transition. Among its main contributions, while the study clarifies the concept of sustainable servitization and provides an initial working definition, it moves from the established idea of SPSS towards linking it to the organizational change process that results in such a sustainable offering to capture incremental strategic changes that contribute to sustainability.	Future research must examine the role of digitalization in embedding sustainability into servitization strategies and the role of innovation management in enabling such a complex transition, considering broader environmental and social aspects, as done by Spadafora and Rapaccini (2024) in this special issue. New approaches (e.g., natural resource-based view) can complement traditional ones (e.g., dynamic capabilities) to understand sustainable servitization and its drivers and industry specificities.
Sousa Zomer et al. (2024). Investigating Social and Environmental Hotspots Throughout the Lifecycle of Product-Service Systems in the Early Design Stages.	Review, plus conceptual development and quantitative expert assessment.	The paper presents a hotspot analysis framework, which combines life cycle assessment techniques for early-stage identification and analysis of potential life cycle stages most susceptible to significant environmental and social impacts within a PSS's life cycle, supporting decision-making in the early design phase and guiding toward experts' sustainable solutions.	The three pillars of sustainability (environmental, social, and economic) must be integrated for a more complete life cycle evaluation in PSS design. Also, the practical application of the hotspot analysis must be expanded to identify real-life encounters that design teams might face.
Bressanelli, Saccani, and Perona (2024). Are digital servitization-based Circular Economy business models sustainable? A systemic what-if simulation model.	Simulation (what if model applied to a digital servitization scenario)	This study adopts a systemic micro-macro perspective to provide a model and a tool applied to a digital servitization-based circular economy scenario based on evidence from the electrical and electronics equipment industry. The paper suggests that digital servitization can result in a win-win situation with net positive environmental effects when it draws on the combined implementation of product design for digitization and life extension, pay-per-use business models, and product reuse.	The validation of the what-if simulation model calls for several applications to other products, industries, and supply chains to confirm its efficacy. Also, further research using dynamic simulation techniques is needed to examine feedback mechanisms (e.g., the law of demand or product obsolescence). Moreover, the model can be used to compare different CE scenarios and assess their specific and combined sustainability impacts to understand which actions have more significant potential regarding sustainability impacts. Finally, further research is needed concerning direct, indirect, and macroeconomic rebound effects.
Sarancic, Pigosso, and McAloone (2024). Evaluation and instantiation	Empirical (qualitative,	The article presents a quantitative and qualitative assessment of a newly suggested generic process model (GPM) for designing sustainable PSS against eight criteria while identifying and proposing solutions to the challenges posed by its application in capital goods	Future studies should involve longitudinal data to assess the potential of the PSS concept emerging from the model presented in the paper while also moving beyond the early stage of PSS design and including

Article	Type	Contribution to the literature	Areas for future research
of a generic process model for early-stage sustainable product-service system design within three manufacturing companies.	multiple case study)	manufacturing firms. The paper also suggests guidelines for the instantiation of the GPM, which are intended to facilitate the translation of GPM into pragmatic models for PSS design practitioners, thereby increasing their chances of success and impact.	information and communication flow and the role of digital technologies in the analysis.
Opazo-Basáez, Bustinza, and Molina (2024). The Effect of Industrial Solution Services (ISS) on Innovation Performance: The Moderating Role of the Sustainable Development Goals (SDGs).	Empirical (quantitative, linear regression)	The research explores the driving factors influencing the innovative performance of servitizing manufacturing firms in OECD countries. The paper investigates the effect of firm industrial solution services-related (ISS) strategies (digital, operational, and green), considering firm competitiveness factors and the impact of the Sustainable Development Goals (SDGs) in each country. While the study shows that a digital ISS strategy can lead to enhanced innovation performance without consideration for the SDGs, operational and green ISS strategies are conducive to innovation performance in companies operating in countries with a higher degree of SDG compliance.	Factors such as technological infrastructure and knowledge management mechanisms should be added to understand the relationship between ISS and innovation performance. Additionally, the quantitative evidence from the study may benefit from qualitative studies to better address how unobservable mechanisms operate in different contexts. Also, evidence based on a longitudinal examination of the relationships must still be generated.
Vaillant and Lafuente (2024). Digital versus non-digital servitization for environmental and non-financial performance benefits.	Empirical (quantitative, regression)	The article scrutinizes the contribution of digital servitization to firms' environmental performance, considering the above potential impact beyond the impact of servitization alone for other non-financial operational, competitive, and customer-oriented performance outputs. The study concludes that digital servitization practices significantly contribute to firms' environmental performance.	Using complementary performance measures to explore how digital servitization simultaneously leads to various outcomes, particularly environmental outputs, and whether those outcomes are synergetic or antagonist regarding the aggregate results. While evidence based on a longitudinal examination of the impacts of digital servitization on environmental performance must still be generated, adding alternative control variables, adopting multi-level and microfoundational perspectives, and analyzing different contexts are tasks for future studies.
Sgambaro, Chiaroni, and Urbinati (2024). The design and servitization of products according to the circular economy principles: An ecosystem perspective in the building industry.	Empirical (qualitative, action research)	The paper analyzes the collaborations between companies in transitioning from a linear to a circular economy in the construction sector's ecosystem, involving circular product design and servitization practices. The authors argue that the engagement of the entire business ecosystem is essential in fragmented sectors to implement product design and servitization practices, which are increasingly enabled by digital technologies.	Besides expanding the geographical and industry scope, further research must examine alternative contractual mechanisms and arrangements that ensure a long-term perspective and goals to understand how collaboration may change as the circular product progresses through life cycle phases and how to ensure long-term alignment and consistency between all ecosystem stakeholders.
Seclen-Luna, Galera-Zarco, and Moya-Fernández (2024). Technological innovation and eco-efficiency in manufacturing companies: Does Co-innovation orientation matter?	Empirical (quantitative)	The study investigates practices for developing innovations to achieve greater eco-efficiency in manufacturing and examines the impact of technological innovation on eco-efficiency and the role of co-innovation orientation concerning suppliers and customers. The results show a positive relationship between technological innovation and eco-efficiency, with process innovation having the strongest effect. Co-innovation with suppliers is more effective as an eco-efficiency driver through product and process innovation, while co-innovation with customers drives eco-efficiency more effectively through product-service innovation. Interestingly, co-innovation with suppliers boosts eco-efficiency for companies that co-innovate with customers but not otherwise.	The authors provide a few methodological routes to improve the understanding of the phenomenon. For instance, future research should expand the scope of the co-innovation orientation to include other stakeholders and generate evidence based on longitudinal data. These stakeholders could provide novel and complementary viewpoints and consider objective measures to provide a more robust and nuanced understanding of the phenomena under study.

4. Concluding remarks and future research

This editorial provides insights into understanding how sustainable servitization has emerged and developed from the literature on PSS, particularly SPSS (Manzini et al., 2001; Manzini and Vezzoli, 2003; Roy, 2000), and some initial conceptualizations provided by servitization academics (Marić and Opazo-Basáez, 2019; Opazo-Basáez et al., 2018; Spring and Araujo, 2017). In so doing, this reflection and the collection of papers included in the special issue can support the advancement of future research by providing common grounds for conceptual discussion and guidelines for creating more profound debates. Enlightenment of sustainable servitization and assimilation of related themes and concepts can also support policymakers when designing instruments and incentive systems towards sustainable industrialization and help managers improve sustainable product-service implementation.

While many topics emerge as targets for future research, we cannot produce an exhaustive list. Still, based on our review and the papers in the SI, we can provide some ideas, guidelines, and broad areas for further research. First, the conditions, antecedents, drivers, and mechanisms for achieving sustainable servitization call for additional explorations, as the potential outcomes do (Kohtamäki et al., 2024). The circumstances under which digital servitization contributes to sustainability and circularity are still unclear. Second, the role of market conditions (and market potential) and different stakeholders in empowering PSS circularity, moving beyond the idea of circular supply chains (Kühl et al., 2019) and the ideas of dematerialization and closed loops in supply chains toward an orchestration of the ecosystem (Parida et al., 2019) by creating a network of relationships involving multiple activities such as reverse logistics (Spring and Araujo, 2017). Third, design for sustainability and circularity requires more evidence and tools. Fourth is the life-cycle assessment of different PSS's sustainability and circularity potential (including sales and customers' viewpoints). Fifth, the process of business model innovation for implementing sustainable servitization and circular PSS. Sixth, PSS's environmental, economic, and social value. Scholars draw on particular technically oriented conceptual approaches to examine a relatively small number of PSS-related specific dimensions and themes, where the dissemination of outcomes is limited to some particular journals, therefore exerting limited influence on the broader servitization community.

Finally, although servitization and PSS are associated with sustainability improvements, their relative capacity for change remains unclear. Enhancements are typically analyzed from a micro and isolated perspective if the aggregation of minor enhancements will result in a significant environmental and social impact. But is this truly the case? This editorial proposes that a macro-level perspective should complement a micro-level analysis. Specifically, future research should examine the role of servitization in the broader context of global environmental sustainability changes: Is servitization a vital, complementary, or marginal component to explain aggregate sustainability improvements?

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