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ORIGINAL PAPER



Sustainable smart product-service systems: a causal logic framework for impact design

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Abstract

Digital technologies can elevate product-service systems (PSS) to smart PSS, which focus on performance rather than ownership and are considered a means for dematerialization. However, transitioning to smart PSS does not guarantee sustainability. To understand the impact of smart PSS holistically, we take a two-pronged approach. First, we use the theory of change to conceptualize the causal link between sustainable smart PSS and their ultimate impact. We develop a three-step causal logic framework consisting of design, causation, and impact. Within this framework, we identify the business model properties of sustainable smart PSS as design characteristics and categorize the eventual impacts based on the triple bottom line. We introduce the term *multi-causal pathway* to describe the causation processes underlining the possibility of non-linearity and multi-causality. Second, we conduct a systematic literature review to investigate the mechanisms linking design and impact. Based on an analysis of 63 publications, we identify 17 specific mechanisms and group them into four types: information, resource, empowerment, and adverse mechanisms. Visualizing our results, we develop a morphological box as a toolkit for managers to develop their own impact-oriented logic model by identifying and activating the multi-causal pathway that fosters the desired sustainability effects. Moreover, discussing our framework, we develop research propositions and managerial questions for impact design. By linking the theory of change with the business model impact, we contribute toward a conceptual synthesis for understanding the impact of (sustainable) smart PSS.

Keywords Sustainability \cdot Smart technology \cdot Product-service system \cdot Theory of change \cdot Logic model \cdot Business model \cdot Morphological box

JEL Classification $M14 \cdot O14 \cdot O32 \cdot Q01 \cdot Q56$

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1 Introduction

Smart product-service systems (PSS) represent a type of business model that integrates smart products and services into a solution bundle (Valencia et al. 2015). Using digital technologies to create and deliver PSS (Liu et al. 2020), it "continuously strives to meet individual customer needs in a sustainable manner" (Zheng et al. 2018, p. 660). Different ownership configurations incentivize providers to design products for resource efficiency and longevity (Bressanelli et al. 2018). Therefore, smart PSS are discussed as facilitators of sustainability (Ingemarsdotter et al. 2019). However, the transition to smart PSS does not guarantee sustainability. Rebound effects and shifts of effects between lifecycle stages can cause detrimental sustainability impacts (Kjaer et al. 2019). Although the sustainability of (smart) PSS has been an academic topic for two decades now (Tukker 2015), a thorough understanding of the sustainability impacts of smart PSS is still lacking (Barravecchia et al. 2021).

Therefore, more research is needed on the sustainability impacts of smart PSS and the role of sustainability within these business models (Kohtamäki et al. 2019). Blüher et al. (2020) recently reviewed the sustainability effects of PSS. However, they did not examine the role of digital technologies but identified their application for sustainability assessment as a research opportunity. While initial approaches to assessing the sustainability of smart PSS exist (Liu et al. 2020), a holistic model that conceptualizes the relationship between sustainability, digital technologies, and PSS business model properties (BMPs) and the impacts they induce is still lacking. Despite emerging research on impact and rebound effects, the causation of sustainability impact is often treated as a black box where business models automatically translate into sustainability effects. From this gap, we derive our overarching research question:

RQ1: How do sustainable smart PSS lead to sustainability effects?

To address this question, we adopt a conceptual approach introducing the theory of change (Carman 2010; Funnell and Rogers 2011) deducing a three-step causal logic framework that links design, mechanisms, and impacts. In the *design* step, innovators define the BMPs. These are a set of rules or characteristics that, when applied, can activate mechanisms. In *causation*, different mechanisms determine the direction and type of effect. Finally, *impact* describes the sustainability effects resulting from the mechanisms. Although this sequence appears unidirectional, feedback loops and interdependencies are common (Funnell and Rogers 2011, p. 189). To emphasize potential non-linearity and multi-causality, we introduce the term *multi-causal pathways*. By representing impacts as a series of steps, multi-causal pathways focus on understanding the series' key elements, their relationships, and linkages to help identify the conditions under which specific sustainability effects occur.

Extensive research is available on BMPs (design characteristics) and the sustainability effects of (sustainable) smart PSS (impact characteristics). For the design step, we synthesize this knowledge and conceptualize sustainable smart PSS as three-dimensional business models that combine sustainability

orientation, PSS, and smart technology BMPs. Similarly, regarding impact, we use the extant literature to categorize the sustainability effects that arise from the BMPs. Within our causal logic framework, we thus develop the design and impact characteristics conceptually. However, concerning the causation step, research usually fails to clearly distinguish between mechanisms and their sustainability impacts. Moreover, the literature is scattered across different research disciplines. Hence, causation, which explains the mechanisms that lead from design to actual impact, is mostly a black box. To open it, we derive the following sub-question:

RQ2: What mechanisms lead from sustainable smart PSS to actual sustainability impacts?

To address RQ2, we conduct a systematic literature review (SLR). Our SLR, which sheds light on causation within our logic framework, identifies 17 mechanisms that we group into four types: information, resource, empowerment, and adverse mechanisms. Integrating our answers to RQ1 and RQ2, we develop a morphological box visualizing the characteristics of design, causation, and impact. Thus, by conceptualizing the causal link between sustainable smart PSS and their impact based on the theory of change and constructing four types of mechanisms based on our SLR, we engage in theory extension, which "borrows theory from outside the field, thereby enriching studied content and broadening the available theoretical repository" (Seuring et al. 2021, p. 5).

By linking the theory of change with business model impact, we advance the conceptual understanding of the effects caused by (sustainable) smart PSS. Our research propositions direct academic attention to the theory of change as a valuable perspective on sustainable impact. For managerial practice, our morphological box provides a toolkit to develop logic models, while our checklist with guiding questions for impact design can assist in innovating impact-oriented sustainable smart PSS.

Our paper is structured as follows. We start by conceptualizing our three-step causal logic framework before describing our SLR methodology. In our results, we first share a comprehensive mapping of the academic literature. Second, we develop a morphological box that constructs four types of mechanisms between design and impact. Discussing our results, we develop research propositions as conceptual synthesis and impact design questions to guide practice. Finally, we address the limitations, future research, and contributions.

2 Conceptualizing multi-causal pathways based on the theory of change

While the business model is a valuable framework for describing mechanisms of value creation, delivery, and capture (Teece 2010), it does not provide guidance for analyzing the causation of sustainability effects. Sustainable smart PSS BMPs result in sustainability effects, but how does this happen? To understand this relationship, we draw on a concept from a related discipline. In non-profit management, logic models based on the theory of change are used to evaluate programs and interventions (Carman 2010; Funnell and Rogers 2011). The theory of change examines how actions lead to the desired impact, requiring managers to define impact goals,



Fig.1 Conceptualizing our causal logic framework (own illustration based on Wagner et al. (2021, p. 1144))

determine what mechanisms lead to goal achievement, and validate this logic of theorized relationships by engaging with internal and external stakeholders (Epstein 2014, pp. 104–106). This approach offers various benefits, including orchestrating consensus on actions and goals among stakeholders, identifying and testing hypothesized relationships, and focusing indicators on these assumptions and outcomes (Weiss 1995).

A logic model articulates this theory by providing a solid outline of "how the program will work under certain conditions," telling the story of the expected impact (McLaughlin and Jordan 1999, p. 66). The logic model distinguishes between inputs, outputs, and impact (Carman 2010; Funnell and Rogers 2011). Inputs describe the resources dedicated to a program, outputs are the immediate product of implemented resources, and impact represents the resulting effects (Carman 2010; OECD 2002). Thus, the logic model displays the individual steps in a sequence of results (Epstein 2014, pp. 104–106), showing "the assumed or hypothesized cause-and-effect or contingency relationships" (Funnell and Rogers 2011, p. 177). Beyond non-profit management, it has been applied in various contexts, such as in cross-sector partnerships (Hansen et al. 2010; Hansen and Spitzeck 2011), impact entrepreneurship (Ney et al. 2014), and the impact of university programs (Wagner et al. 2021). Because of this broad application, the theory of change is helpful for understanding the relationship between sustainable smart PSS and their impact.

Following this idea, innovators need to define shared impact objectives, determine which BMPs lead to the desired impact-generating mechanisms, and, finally, verify the relationship assumed first in theory through stakeholder engagement and later in practice using indicators of the mechanisms and effects. To do this, we conceptualize a three-step causal logic framework, opening the black box between design and impact (see Fig. 1). Mirroring the logic model's inputs, the initial *design step* focuses on how innovators define the BMPs of sustainable smart PSS. In the *causation step*, which corresponds to the logic model's output, a change in resources, knowledge, values, or behaviors occurs. Finally, just as in the original logic model, *impact* occurs when sustainability effects occur. As noted earlier, this three-step distinction implies neither mono-causality nor linearity. To acknowledge the interplay of multiple causes and feedback loops (Funnell and Rogers 2011, p. 189), we introduce the term *multi-causal pathways* and define them as the processes by which business models contribute to specific sustainability effects through a series of steps.

Thus, one or multiple BMPs initiate one or multiple mechanisms. A mechanism may be initiated *directly* by design or *indirectly* caused through feedback loops. Furthermore, a single mechanism may directly cause an effect or initiate a cascade of mechanisms that cause an effect. Subsequently, a mechanism causes one or multiple sustainability effects. This effect may be positive or negative, intended or unintended regarding the desired impact. An effect may be *directly* caused by a mechanism or *indirectly* caused by a previous effect, such as lower emissions caused by reduced energy consumption. Finally, if multiple mechanisms influence an effect, it is *multi-causal* compared to a *mono-causal* effect determined by a single mechanism. For example, CO₂ savings can be a multi-causal effect resulting from a shift to product sharing, which requires fewer products to be manufactured, and predictive maintenance, which allows for longevity rather than replacement, which also avoids manufacturing emissions. However, the lower costs for product sharing could induce rebound effects. Thus, within a multi-causal pathway, there may be interlinked parallel sequences and feedback loops. When incorporating feedback loops, only those that are critical to the target impact should be outlined, as showing that everything is related to everything contradicts the logic model's intention of understanding mechanisms (Funnell and Rogers 2011, p. 187).

Thus, our framework contributes to the innovation literature by separating two perspectives on sustainability. We distinguish between sustainability as a design principle that specifies the target function of the innovation (Dzhengiz and Hockerts 2022) or the goal innovators want to achieve (Epstein 2014, p. 104) and sustainability as an actual effect that represents the impact function.

2.1 Design: business model properties of sustainable smart PSS

In the design step, innovators define the BMPs of sustainable smart PSS. These are a set of rules or characteristics that, if applied, are the inputs that give rise to mechanisms. However, knowledge on the role of sustainability and digital technologies in PSS business models and a consensus on what makes a business model a sustainable smart PSS business model are lacking (Kohtamäki et al. 2019). Addressing this gap, we conceptualize sustainable smart PSS as three-dimensional business models that combine sustainability orientation, smart technologies, and PSS BMPs by design (see Fig. 2).

2.1.1 Sustainability orientation

Sustainable business models "seek to go beyond delivering economic value, including the consideration of other forms of value for a broader range of stakeholders" (Bocken et al. 2013, p. 484) and explicitly address the triple bottom line (TBL) (Schaltegger et al. 2012).

Conducting an SLR, Geissdoerfer et al. (2018) identified three design characteristics of sustainable business models: sustainable value, pro-active multi-stakeholder management, and a long-term perspective. However, the term *sustainable value* is conceptually ambiguous (Cardoni et al. 2020) and often misused (Widmer



Fig.2 The BMPs of sustainable smart PSS (own illustration summarizing the three related literature strands)

et al. 2018), referring to different components of the business model (Méndez-León et al. 2022). To be more precise, we use the term *multidimensional value proposition*. Here, the term *multidimensional* refers to the fact that the value proposition relates to the creation of value and the mitigation of disvalue regarding economic, ecological, and social dimensions for a diverse set of stakeholders (Beckmann and Schaltegger 2021; Evans et al. 2017). The term value *proposition* emphasizes the *intended* sustainability outcomes, not the impact ultimately realized. Similarly, when applied to the design phase, the BMP of pro-active multi-stakeholders. In the same way, we interpret the long-term perspective as considering the *lifecycle orientation* of the offering. To summarize, we conceptualize the BMPs of the sustainability orientation based on the multidimensional value proposition, stakeholder co-creation, and a lifecycle orientation.

2.1.2 Product-service systems

PSS refer to bundles of products and services intended to satisfy customer needs (Goedkoop et al. 1999; Mont 2002). With increasing servitization, PSS shift from a product focus to access and performance (Tukker 2004). Different ownership configurations give providers an incentive to internalize externalities throughout the product lifecycle, aligning economic and environmental benefits (Tukker 2015). Thus, PSS design follows a different logic than product design: retaining product

ownership, assessing the total cost of ownership rather than product and production costs, and designing for circularity rather than failure (Tietze and Hansen 2013).

Tucker's three types of PSS are the most common distinctions (Bressanelli et al. 2018), including product-oriented, use-oriented, and result-oriented PSS (Tukker 2004). Product-oriented PSS offer an additional service to complement the product, such as maintenance, take-back, or advice and consultancy, e.g., on use efficiency. Use-oriented PSS comprise product leasing, product sharing or renting, and product pooling. Finally, result-oriented PSS deliver a functional performance rather than a classical product. Kjaer et al. (2019) identified five business actions enabled by the three PSS types: operational support, product maintenance, end-of-life (EOL) management, product sharing, and optimized result. While Tukker's (2004) three PSS types examined the degree of servitization, the framework by Kjaer et al. (2019) addressed what function a service delivers to understand how this contributes to sustainability. Note that product sharing is congruent with the use-oriented PSS and optimized result with the result-oriented PSS. By contrast, operational support corresponding to advice and consultancy, product maintenance, and EOL management, including take-back, can be part of product-oriented, use-oriented, and result-oriented PSS. The focus on functions is more tangible, allowing for a more precise attribution of design characteristics and sustainability impact. Hence, we conceptualize the BMPs of PSS based on the extension of Tukker's typology by Kjaer et al. (2019), defining the PSS BMPs of operational support, maintenance, EOL management, product sharing, and optimized result.

2.1.3 Smart technologies

Smart PSS integrate smart products and services to jointly meet customer needs (Valencia et al. 2015). Various digital technologies enable combining sensorequipped products and data-driven services, including IoT, cloud computing, big data analytics, and digital twins (Zheng et al. 2019b). For example, Hewlett-Packard complements smart printers with a service that monitors toner levels and orders new cartridges just in time to increase uptime and cost-effectiveness (Boldosova 2020).

Engineering research generally distinguishes between offline and online smartness, and the communication between them based on connectivity. While offline smartness refers to physical smart PSS equipped with sensors and actuators to perceive the environment and adapt accordingly, online smartness refers to virtual smart PSS and their ability to process information based on big data analytics and algorithms (Li et al. 2021a, b; Zheng et al. 2018). We build on these dimensions, complementing each with two characteristics focusing on *how* smartness is reflected in the business model (see Fig. 3). Offline smartness includes *sensing*, describing the collection of data through sensors (Lenka et al. 2017; Parida et al. 2019), and *adaptability and autonomy*, referring to the ability to respond to the physical environment and operate in an independent, goal-directed manner (Alcayaga et al. 2019; Lenka et al. 2017; Li et al. 2021a, b; Rijsdijk and Hultink 2009; Zheng et al. 2018). The interaction characteristic includes *connectivity*, which is the transmission of collected data through wireless communication (Cong et al. 2020; Lenka et al. 2017; Parida et al. 2019), complemented by the characteristic of *data integration*,





the ability to record and integrate data stored in a cloud system, which enables feedback (Alcayaga et al. 2019; Cong et al. 2020). Finally, online smartness consists of *analytics*, transforming collected data into insights (Alcayaga et al. 2019; Cong et al. 2020; Lenka et al. 2017; Parida et al. 2019), and *virtuality*, referring to the product or service in the cyberspace (Zheng et al. 2018).

2.2 Causation: a black box

In causation, mechanisms lead from design to actual impact. However, this is a blind spot because the causation of sustainability impacts is often treated as a black box where business models simply translate into certain sustainability effects. This results from two issues. First, research often fails to distinguish between mechanisms and sustainability effects (Allen Hu et al. 2012; Schöggl et al. 2017). Second, research is scattered across the fields of engineering, sustainability, and innovation management. To bring the literature together systematically and open the black box, we conduct an SLR that zooms into this crucial but understudied part of the causal logic framework.

2.3 Impact: sustainability effects

Impact is where sustainability effects materialize. One framework for measuring this performance from a stakeholder perspective is the Sustainable Balanced Score Card (SBSC), which distinguishes among the four perspectives: finance, customers, internal processes, and learning and growth (Hansen et al. 2010). However, critics point out that the instrumental understanding of social and environmental aspects is geared toward profit and linear architectures, as opposed to sustainability's complexity (Hahn and Figge 2018). SBSC proponents indicate that the framework can reflect non-instrumental objectives, such as the TBL, and non-linear architectures (Hansen and Schaltegger 2018). The TBL is another framework based on the stakeholder perspective, which extends the firm's responsibilities beyond the economic aspects of meeting customer needs profitably (Hubbard 2009). Elkington (1998) introduced the TBL, which adds a social and environmental dimension to economic performance. While the TBL is popular in practice, scholars criticize the framework for its lack of measurability and novelty, as standard-setting bodies such as the Global Reporting Initiative (GRI) had already introduced global social and environmental performance

measures (Norman and MacDonald 2004). Recently, Elkington recalled the concept because it did not live up to his intention of encouraging social and environmental value addition but rather converged these two dimensions to play a role in profit-making (Elkington 2020, pp. 29–33). A more recent framework introduced in 2015 is the 17 Sustainable Development Goals (SDGs) with 169 sub-goals, including performance indicators (Gusmão Caiado et al. 2018). However, the SDGs have also been criticized for inconsistencies and incompatibilities between goals, especially between environmental sustainability and socioeconomic progress, their broad scope, lack of prioritization, and difficulties in quantification and implementation (Swain 2018).

As all frameworks have weaknesses, we rely on the TBL to operationalize sustainability effects within our causal logic framework because this approach best aligns with the accepted understanding of sustainable business models (Bocken et al. 2013; Schaltegger et al. 2012). Moreover, the TBL is widely used in research on the sustainability effects of smart PSS (Blüher et al. 2020; Lee et al. 2012; Song et al. 2021; Zhu and Hu 2021). Furthermore, our definition of the *multidimensional value proposition* and the integrated concept of value creation and disvalue mitigation (Beckmann and Schaltegger 2021) encompass the TBL's two sides of benefits and losses. However, to address valid criticism, we use the more specific GRI indicators as subcategories for the three pillars (GRI 2021).

3 Methods

To identify the mechanisms that lead from design to impact, we conducted an SLR, defined as a structured method designed to "synthesize research in a systematic, transparent, and reproducible manner" (Tranfield et al. 2003, p. 207). Typically, the method involves quantitative descriptive and qualitative thematic analyses, and employs a structured multi-step process (Tranfield et al. 2003). We followed Tran-field et al. (2003) with a four-step process (see Fig. 4).

In the first step, we designed our search string. Based on a scoping study, we identified the keywords for the search procedure based on research field's key literature. As a result, we derived one search string consisting of the four search clouds *sustainability*, *smart*, *PSS*, and *innovation* and related keywords (see Table 1). The targeted papers were required to match at least one keyword (OR operator) in each cloud (AND operator), and the resulting search string was adapted to the specific requirements of each database. For example, our search string for Scopus was:

TITLE-ABS-KEY((sustainab* OR environ* OR eco* OR green OR ecoefficiency OR social OR societal OR ethic* OR csr OR corporate sustainab* OR "sustainable development" OR circular* OR closed-loop OR ecolog* OR resource* OR "life cycle assessment" OR lca OR stewardship OR responsib* OR fair) AND (smart* OR digital* OR data-driven*) AND (pss OR "Product-Service System*") AND (innovat* OR process OR engineering OR design* OR value OR collaborat* OR approach OR framework OR tool OR method* OR "Business Model"))



Fig. 4 Systematic literature review process

The first three clouds represent the three business model dimensions of sustainable smart PSS. We decided to include different perspectives and levels of sustainability to cover them as comprehensively as possible. We used the keywords from Klewitz and Hansen (2014) that are often used for SLRs, e.g., Wehnert and Beckmann (2021), and added circular, closed-loop, ecolog*, resource*, life cycle assessment, LCA, stewardship, responsib*, and fair. The smart and PSS word clouds are based on the SLR by Zheng et al. (2019b) and are well-defined. The fourth cloud well-defined. The fourth cloud addresses the innovation of sustainable smart PSS, as our SLR aims to build mechanisms that link design and impact. In the innovation process, design is key to creating a net-positive sustainability impact. The inclusion of the fourth cloud follows our proposed causal logic. Moreover, we explicitly included the term *framework* to identify relevant approaches to analyze sustainability effects. Since this cloud does not build on previous SLRs, we derived matching keywords from the literature and performed several trial runs in the databases. In addition to the keywords shown in the fourth cloud, we tried terms such as building or cooperation. However, these did not yield any additional hits and were subsequently dropped.

We conducted the SLR in October 2020 and an update in May 2022, considering peer-reviewed articles and conference papers in English. The search was conducted in the three online databases Web of Science, Scopus, and Ebsco, owing to their relevance, particularly in the fields of sustainability management and engineering. The search for keyword hits was limited to the title, abstract, and keywords for

Table 1 Keywords operationalized for the SLR				
Search Clouds				Operators
Sustainability sustainab*, environ*, eco*, green, eco-efficiency, social, societal, ethic*, CSR, corporate sustainab*, 'sustainable development'', circular*, closed-loop, ecolog*, resource*, "life cycle assessment", LCA, stewardship, responsib*, fair	Smart smart, digital, data- driven	PSS, "Product- Service Sys- tem*"	Innovation innovat*, process, engi- neering, design*, value, col- laborat*, approach, frame- work, tool, method*, "Business Model"	AND OR

publications until 2021. This search strategy yielded 505 hits across all databases after removing duplicates.

Second, we applied selection criteria to identify publications for further analysis. Inclusion criteria were a clear contribution to all four search clouds. Exclusion criteria were a lack of clear contribution and a different meaning of PSS. As this is still a nascent stream, we did not include any quality criteria other than the peer-review status to capture the literature as holistically as possible. Two researchers of the team conducted the initial identification based on the selection criteria applied to the title, abstract, and keywords to ensure thematic relevance. Articles with divergent ratings were discussed according to the criteria until a consensus was reached. Based on the selection criteria, we identified 98 articles for further analysis.

Third, an ABCD ranking was developed based on full texts, following Klewitz and Hansen (2014). This involved analyzing the extent to which the texts made relevant contributions to the triad of sustainability, smart technologies, and PSS while remaining relevant to the innovation process. An A rating was given for considering this triad, whereas papers with limited sustainability or smart technology consideration were given a B rating. The sum of the articles with an A rating (21) and a B rating (28) was further analyzed to answer our RQs. Articles with a C rating, a total of 44 records with no clear sustainability contribution, and a D rating, five conference paper versions of journal articles already included in the sample, were excluded.

Lastly, we manually included 14 additional relevant publications cited in our sample but not identified by the search process (i.e., snowball sampling). In total, we identified 63 articles for our analysis (see Appendix A for a sample overview).

We performed the descriptive analysis using the data extraction sheet to map the research field of sustainable smart PSS. This sheet is available to readers upon request. For the thematic analysis, we conducted a qualitative content analysis following Mayring (2015) using MAXQDA. The distinction between design, mechanism, and impact guided our coding process. As we conceptually developed the design and impact step of our causal logic framework, the code categories for the BMPs and the sustainability effects were developed deductively. We refer to Sect. 2 for a detailed derivation. For the causation step, we focused on the mechanisms as a link between design and impact to understand how the BMPs of (sustainable) smart PSS lead to sustainability effects. Based on inductive open coding, we coded all mechanisms within the articles and systematically consolidated them. As a result, we identified 17 individual mechanisms, which were then aggregated into higherorder categories to form four types of mechanisms: *information, resource, empowerment*, and *adverse* mechanisms (see Table 2). All three researchers discussed the codes and their aggregation.

To create our causal logic framework for impact design, we develop a morphological box. "The term 'morphology' is used in a number of scientific disciplines to refer to the study of the structural relationships between different parts or aspects of the object of study [...] [and] the 'morphological approach' [serves] as a method for exploring all possible solutions to any type of multi-dimensional, essentially nonquantified problem complex" (Álvarez and Ritchey 2015, p. 1). While previous literature has used morphology to generate design options for sharing or circular business models (Curtis and Mont 2020; Lüdeke-Freund et al. 2019), our morphological

Design: Business Model Properties		Causation: Mechanisms	Impact: TBL Effects, following GRI					
Sustainability Orientation		A. Information Mechanism	Economic	+	-			
Stakeholder Co-Creation	0	A1. Product & Material Transparency	Costs	٠	0			
Lifecycle Orientation	٠	A2. Customer & Use Insights	•	Risk & Uncertainty	•	0		
Multidimensional Value Proposition	0	A3. Information Exchange	0	Profit (Potentials)	•	0		
Smart Technology		A4. Process Optimization	•	Quality	•	0		
Sensing	•	A5. Improved Design	•	Customer Relation	•	0		
Adaptability & Autonomy	0	B. Resource Mechanism	Standards & Cooperation	0				
Connectivity	•	B1. Material Efficiency	Ecological					
Data Integration	٠	B2. Operational Efficiency	0	Resource Consumption	•	0		
Analytics	•	B3. Intensified Use		Emissions & Pollutants	0	0		
Virtuality	•	B4. Product Longevity	•	Waste O O				
Product-Service System		B5. Modularity, Upgrade-, and Updateability	Social					
Behavioral Support*	0	B6. EOL Reallocation & Recovery	0	Human Rights & Equality				
Operational Support	•	B7. Product System Substitution	0	Labor Practices & Safety				
Maintenance	•	C. Empowerment Mechanism	Product Stewardship O O					
EOL Management	•	C1. Broader Access		Society	0	0		
Product Sharing	•	C2. Increased Customer Interaction		Legend				
Optimized Result	0	C3. Customer Stewardship Behavior						
		D. Adverse Mechanism	Medium prominence () Low prominence ()					
*This characteristic is a result of our co process.	ding	D1. Careless Customer Behavior						
		D2. Rebound & Rebalancing Effects						

Table 2 Overview of codes and sub-codes including a heat map indicator for their prominence in the literature

Regarding impact, the plus sign (+) indicates a positive effect, while the minus sign (-) denotes a negative effect on the TBL

box goes beyond business model design options constituting a framework for impact design. It visualizes all options identified in the literature for the design and impact characteristics and the mechanisms linking the two, and thus represents a logic modeling tool for managers to identify multi-causal pathways and test hypothesized relationships regarding the impact of sustainable smart PSS in business model innovation.

4 Results

We used the SLR in three ways. First, we conducted a quantitative descriptive analysis surveying the research field. Second, we mapped the literature to reveal the focus of the academic discussion and to identify blind spots and future research avenues. Third, based on a qualitative thematic analysis, we identified the mechanisms that lead from design to impact, thus finalizing our causal logic framework.

4.1 Quantitative descriptive results

Our SLR shows that sustainable smart PSS have been gaining momentum since 2017 (cf. Fig. 5). However, little research has been published in high-ranked journals; the majority has been published in conference proceedings such as Procedia CIRP (cf. Fig. 6) indicating that the current debate is still nascent. The debate started in the engineering discipline and is slowly moving into journals that span



0 5 10 15 20 25

Model Application

Fig. 7 Distribution of reviewed publications over methodology

the boundaries of sustainability and management, such as *Sustainability* and *Journal of Cleaner Production* (this result needs to be seen in the light of the rapid increase of articles published by these journals). This finding is congruent with similar SLRs, such as on smart remanufacturing (Kerin and Pham 2020).

30 35

The articles identified in our SLR are mostly conceptual papers or case studies (cf. Fig. 7). There are only two quantitative empirical studies by Firnkorn and Müller (2011, 2012) analyzing the environmental impact of car-sharing. Note that many case studies result from 15 conceptual papers that illustrated their developed concepts based on a use case. The applied methodologies also support the suggestion that research on sustainable smart PSS is still nascent.

We identified two main concepts that the reviewed studies frequently used: the business model and the lifecycle perspective (cf. Fig. 8). Moreover, many studies outlined capabilities but did not refer to the theory. This is particularly the case for digital technologies and smart capabilities (Alcayaga et al. 2019; Michalik et al. 2018; Pagoropoulos et al. 2017; Zheng et al. 2017, 2018; Zheng et al. 2019a, b). Some authors also addressed more specific technological capabilities, such as IoT (Basirati et al. 2019; Ingemarsdotter et al. 2019) and data leveraging



Fig. 8 Distribution of reviewed publications over theoretical lenses

capabilities (Li et al. 2021a, b). Regarding PSS, the papers addressed internal capabilities, such as organizational and networking capabilities, skills, and learning (Kerin and Pham 2020; Li et al. 2020), design, including interaction (Matsas et al. 2017), customization (Liu et al. 2018), product development (Hallstedt et al. 2020; Stark et al. 2014), and service design capabilities (Fargnoli et al. 2018; Spring and Araujo 2017). Additionally, the service-dominant logic was applied to a limited extent (Chang et al. 2019; Krueger et al. 2015), and design theory was used to develop new frameworks and tools (Song and Sakao 2017; Tao et al. 2019).

However, regarding grand theories, the research field is undertheorized. Only two papers adopted such a theoretical approach. Reim et al. (2018) focused on the agency theory to explore adverse customer behaviors within PSS. Haftor and Climent (2021) analyzed their case through various theoretical lenses, such as the resource-based view, transaction cost economics, and institutional logics. In addition to this theory application, Spring and Araujo (2017) adopted a lifecycle perspective on product biographies and addressed PSS issues related to agency theory, dynamic capabilities, and service-dominant logic. Moreover, it is noteworthy that stakeholder theory, a theory otherwise frequently used in sustainability, was only integrated once in a study outlining a user-centric smart PSS development approach published in the engineering field (Chang et al. 2019). This finding is congruent with prior research. In their SLR, Parida et al. (2019) identified a medium to low level of theoretical maturity in the field of digitalization, sustainability, and PSS. As sustainable smart PSS change actors' roles and their interactions, the lack of theory-driven approaches constitutes a blind spot in current research.

4.2 Mapping the academic literature

In Table 2, the symbols indicate the prominence of each element of our causal logic framework in the literature. The prominence level is based on the frequency

of references within the 63 studies analyzed.¹ They serve as a heat map indicating research gaps in the current literature. In the impact step, the plus sign refers to the value created, while the minus sign refers to disvalue (i.e., negative TBL effects). A detailed mapping of the literature is included in the data extraction sheet. Whether the discrepancy in prominence indicates different levels of maturity or a different real-world relevance of the elements invites further research.

In the *design* step, research has focused more on smart BMPs than on sustainable BMPs. This may result from academia's tendency to look at sustainability as an outcome rather than sustainability by design. While previous research has identified a tendency toward product sharing (Blüher et al. 2020), our SLR identifies the resultoriented configuration as the least researched. One explanation for this finding may be that we deconstructed the category of product-oriented PSS to analyze the different types of service offerings in more detail.

In the *causation* step, we identified a high prominence of *information mecha*nisms and a medium prominence of resource mechanisms. The empowerment mechanisms and the adverse mechanisms appear with rather low prominence in our sample so far. The mechanism of increased interaction (C2) is an exception with generally high prominence. This shows the importance of embracing the change in relationships that sustainable smart PSS induce. Moreover, studies dealing with customer behavior highlight that this is crucial for the impact of sustainable smart PSS because the use phase is often decisive for sustainability effects (Haftor and Climent 2021; Reim et al. 2018; Valencia et al. 2015). Furthermore, rebound and rebalancing effects (D2) are widely recognized issues in the PSS and CE literature (Alcayaga et al. 2019; Kjaer et al. 2019), highlighting the importance of this mechanism. We explain the difference in prominence with the bias of studies that have discussed the positive economic-environmental potential of smart PSS. A frequently cited example is smart technology that facilitates process optimization, resulting in increased profits and environmental contributions (e.g., waste reduction or energy efficiency) (Bressanelli et al. 2018). While such positive cases exist, they neglect the necessary stakeholder engagement and overlook the role of user behavior and unintended undesirable effects. Therefore, we assign high relevance to the empowerment and adverse mechanisms and include them in our causal logic framework. Moreover, we call on academia to focus on the relationship-based empowerment mechanisms and the inherently negative *adverse mechanisms* to broaden the perspective on multicausal pathways and present a holistic picture.

In the *impact* step, our SLR shows that little is known about the specific effects of sustainable smart PSS. In line with Blüher et al. (2020), research generally highlights positive impacts, especially economic effects. However, these are positive impact potentials, as it is often not evident whether these are actually reaped. This is consistent with prior research (Ingemarsdotter et al. 2019). It is also the reason why we explicitly added *potentials* for the economic *profit* criterion. In many cases,

¹ As the highest number of papers, which referred to one element of our model, was 49, we divided 49 by 3 to create three prominence levels. We designated a low prominence for a frequency of references less than or equal to 16, a medium prominence for a frequency of references between 17 and 32, and a high prominence for a frequency of references equal to or greater than 33.

research has identified potentials (Alcayaga et al. 2019; Bressanelli et al. 2018) but has not demonstrated increased profits. In fact, under certain conditions, even negative impact occurs. In addition to the bias toward positive impact, little attention is paid to social impacts (Liu et al. 2020). This finding is consistent with other studies that emphasize society as a value recipient (Kristensen and Remmen 2019). To conclude, the literature currently focuses on the positive economic–environmental dimension of sustainability (La Calle et al. 2021). Therefore, research needs to go beyond costs and consider the social dimension when researching sustainable smart PSS.

4.3 Qualitative thematic results: a causal logic framework for impact design

In the qualitative analysis, we explored the causation step by constructing mechanisms that lead from sustainable smart PSS to sustainability impacts. Our inductive category building aggregates four mechanisms by grouping 17 individual mechanisms into higher-order constructs, namely, information, resource, empowerment, and adverse mechanisms (RQ2). Moreover, we complemented our causal logical framework with novel categories resulting from the SLR. Here, we identified behavioral support as an additional BMP of PSS. Based on this complementary approach, we developed our causal logic framework connecting the three business model dimensions of sustainable smart PSS, as well as their mechanisms and the TBL effects to explain the causal link between sustainable smart PSS and their sustainability impacts (RQ1).

4.3.1 The design step: identifying behavioral support as an additional business model property of PSS

In addition to the BMPs conceptualized earlier in the *design step*, we identified one new BMP of PSS needed to embed the PSS cases we found in the literature. In contrast to operational support, which is a service to support product operation and efficiency, such as staff training, performance monitoring, or automation services, we identified *behavioral support*.

Behavioral support helps end-users reflect, set, and achieve goals, creating value by nudging them toward behaviors with which they have difficulty committing to (e.g., through positive feedback, gamification, incentives, or a community platform). In contrast to operational support, which provides knowledge on efficient usage, behavioral support helps users overcome motivational challenges. Thus, behavioral support refers to user self-management guiding individual actions (Hankammer et al. 2021). An example is the EcoDrive behavioral support for truck drivers, which promotes safe and fuel-efficient driving (Haftor and Climent 2021). The support includes monitoring and feedback, contests, awards, and a community platform for drivers to promote safe and ecological driving, ultimately reducing costs, resource consumption, and emissions while increasing safety. Moreover, the behavioral support BMP is generally based on smart BMPs. For example, Valencia et al. (2015) presented Nike+, a PSS that allows consumers to track their running efforts. The

lodel es	Sustainability Orientation	Stakeholder Co-Creation					Lifecycle Orientation				Multidimensional Value Proposition				
ness N roperti	Smart Technology	Sensi	ng	Adaptability and Autonomy		and y	Connec	Connectivity		Data Integration		Analytics			Virtuality
Busir Pr	Product-Service System	Behavior Support	al t	Operat Supp	ional ort	Ma	intenance		Man	EOL agement		Product Sharing		O	otimized Result
	A. Information	A1. Produ	ict and N	laterial	Transpa	arency	A2	. Custe	omer	r and Use	Insights		43. Info	ormation	Exchange
	Mechanisms		A4. Pi	rocess	Optimiz	ation					A5.	Improved	l Desig	gn	
Mechanisms	B. Resource	B1. Material	B2. B3 Operational Intens		B3. Intensif	fied B5. Modular		arity, L	ity, Upgrade-, and Updateability				B6. EOL Reallocation		B7. Product System
	mechanisms	Efficiency	cy Efficiency I		Use	e B4			. Product Longevity				and Recovery Subs		Substitution
	C. Empowerment	C1. Broader Access					C2. Increased Customer Interaction								
	Mechanisms						C3. Customer Stewardship Behavior								
	D. Adverse Mechanisms	D1. Careless Customer Be				Behavi	havior D2. Rebound and Rebalancing Effects					ts			
TBL Effects	Economic	Costs	Ri Un	Risk and Uncertainty		Pi (Pote	rofit entials)	Quality		lity	Custom	stomer Relation		Standards and Cooperation	
	Ecological	Resource Consumption					Emissions and Pollutants				ints	Waste			
	Social	Human Rights and Equality Labor				bor Pra	Practices and Safety Product Stewa			rdship	Iship Society				

Fig. 9 Causal logic framework for impact design—a sustainable smart PSS impact design tool

behavioral support consists of rewards and prizes to encourage running, such as automated cheering messages from famous athletes after reaching a goal. Other examples are a smart pillbox that reminds users to take their medication (Chang et al. 2019) or a smart fridge with health tracking and recipe recommendations (Liu et al. 2018). Identifying behavioral support complements RQ1.

4.3.2 The causation step: opening the black box to identify mechanisms that link design and impact

This step is the core of our causal logic framework and addresses RQ2. Our analysis constructs 17 individual mechanisms and aggregates them into four types: *information mechanisms (A), resource mechanisms (B), empowerment mechanisms (C),* and *adverse mechanisms (D).* The mechanisms thus represent the (dis)value creation function of the respective BMPs (cf. Fig. 9).

Information mechanisms (A) comprise five individual mechanisms related to the generation, exchange, and use of information. These include product and material transparency, customer and use insights, information exchange, process optimization, and improved design. The first three are prerequisites for the latter two, which build on them, and thus form a first causal link. *Product and material transparency* (A1) describes the identification, traceability, and monitoring of product-related data, such as the product's location, composition, condition, maintenance history, and performance data (Alcayaga et al. 2019). *Customer and use insights* (A2) comprise data on consumption and user behavior (Cong et al. 2020). *Information exchange* (A3) among different stakeholders addresses information sharing and collaboration along the value chain (Li et al. 2020). *Process optimization* (A4) based on information involves increasing performance, availability or uptime, and maintenance efficiency. It also refers to improving internal processes and more efficient use

of resources. The same is true for the mechanism *improved design* (A5) (Bressanelli et al. 2018). Improved design results from the increased availability and feedback of consumer data (A2), which enables better alignment with consumer needs over time and thus value retention (Ingemarsdotter et al. 2019; Valencia et al. 2015). It is therefore directly linked to the *resource mechanisms* (B5) *upgradeability, update-ability, and modularity*, and (B4) *product longevity*.

Resource mechanisms (B) describe the management, exchange, and (post-)use of energy, material, and product flows, including seven individual mechanisms adressing efficiency, intensified product use, product life extension, EOL management, and product system substitution (Kjaer et al. 2019). Efficiency includes material efficiency (B1) in design (Fargnoli et al. 2018), and operational efficiency (B2) in use (Bressanelli et al. 2018). Intensified use (B3) implies increased utilization (Matschewsky 2019). Although it is mainly associated with product sharing, it can also be induced by the BMP optimized result (Kjaer et al. 2019). Extending the product use phase aims at a longer life and includes *product longevity* (B4) (Bridgens et al. 2019), which is an issue for smart PSS in terms of technological obsolescence (Kjaer et al. 2019). As upgradeability, updateability, and modularity (B5) is frequently discussed (Pialot et al. 2017), we represent it as a sub-mechanism of product longevity. In contrast, EOL reallocation and recovery (B6) refers to an improved material and energy cycling. Finally, product system substitution (B7) at the macro-level (PSS) changes how a specific customer need is met, e.g., online communication that eliminates the need for physical transportation. At the micro-level (product), it displaces more resource-intensive products (e.g., substituting conventional with electric carsharing) (Kjaer et al. 2019).

Empowerment mechanisms (C) represent a positive enabler of participation, removing barriers through three individual mechanisms. Broader access (C1) can remove barriers for different stakeholders. The mechanism can link smart BMPs with growth and regional development, especially in remote areas (Parida et al. 2019). Communities can benefit from increased utility access based on product sharing, such as transportation (Blüher et al. 2020). Companies can access assets and services through product sharing within a network (Pan et al. 2019), and long-term service contracts can lead to less economic volatility (Blüher et al. 2020). Increased customer interaction (C2) includes the individualization of services, communication among user communities, and higher service engagement, leading to better customer relationships (Valencia et al. 2015), which directly links to TBL impact. This mechanism embeds two types of interaction. First, the provider-customer interaction, which includes customer co-creation (Liu et al. 2018), customization (Hallstedt et al. 2020), interactive design (A. Q. Li et al. 2020), training (Fargnoli et al. 2018) and providing feedback, such as sending maintenance alerts (Song and Sakao 2017). Second, the customer-customer interaction, which is facilitated by community platforms (Haftor and Climent 2021). Customer interaction enables customer stewardship behavior (C3), which is activated by information that guides users to act responsibly toward the environment, society, and themselves. By providing information and feedback (Valencia et al. 2015), this mechanism enables users to care for energy efficiency (Bressanelli et al. 2018), product longevity (Moreno et al. 2017), or their own health (Valencia et al. 2015). This mechanism results from the PSS BMP of *operational support* and *behavioral support*.

Adverse mechanisms (D) produce negative effects consisting of careless customer behavior and rebound and rebalancing effects. Careless customer behavior (D1) results from the shift in ownership for product sharing and optimized result BMPs. This can lead to a reduced sense of obligation along with less careful use, thus increasing maintenance costs or leading to faster wear and tear, which is detrimental to product longevity (B4) (Bressanelli et al. 2018). Moreover, the theft of shared products can be an issue (Bonilla-Alicea et al. 2020). The behavior can also cause detrimental impacts on society, such as shared scooters blocking sidewalks (Blüher et al. 2020). Rebound and rebalancing effects (D2) address rebound effects, which describe the negative impact resulting from efficiency improvements that lead to increased consumption (Kjaer et al. 2019). Moreover, there may be shifts between lifecycle stages due to negative consumption effects (Kjaer et al. 2016) or trade-offs within a BMP or between different BMPs. An example of such a trade-off between BMPs is the increase in energy consumption and waste caused by smart PSS compared to the potential of sensing and analytics to optimize maintenance processes (Halstenberg et al. 2019). Rebalancing refers to the relocation of shared products, such as bicycles, with the help of vehicles and staff to compensate for asymmetric use patterns (Bonilla-Alicea et al. 2020).

4.3.3 The impact step: the creation of economic, ecological, and social (dis)value

Impact represents a subsequent effect of design decisions translated through a single mechanism or cascades of mechanisms and includes the economic, ecological, and social (dis)value created. Note that the following only reflects the content of key references for each effect and closely related causal links.

Within the *economic* dimension, we distinguish positive effects on *costs* (Haftor and Climent 2021), risk and uncertainty (e.g., through enhanced information availability) (A1-A3) (Pialot et al. 2017), profit (potentials) (Alcayaga et al. 2019), quality, such as fewer errors and interventions through process optimization (A4) (Basirati et al. 2019), customer relationship (Alcayaga et al. 2019), such as better responsiveness to customer needs (A5) (Fargnoli et al. 2019), interactive co-creation (C2) (Li et al. 2021a, b), and standards and cooperation (Alcayaga et al. 2019). The last criterion addresses the need for sustainable smart PSS to adopt a value network perspective that builds partnerships (Haftor and Climent 2021). This requires the sharing of information (A3) (Wellsandt et al. 2017), risk (Spring and Araujo 2017), and resources (C1) (Pan et al. 2019) and, thus, close collaboration and harmonization within the value network (Parida et al. 2019). While research has highlighted the positive effects, the economic impact can also be negative, mainly in terms of costs, such as for increased service and digitalization (Liu et al. 2018), and riskand uncertainty-driven necessary investments (e.g., due to adverse customer behavior (D1) (Reim et al. 2018) when moving toward sharing or optimized result BMPs (B7) (Kölmel et al. 2015), and an unknown product's residual value (B6) (Ingemarsdotter et al. 2020)).

The *ecological* dimension includes effects on *resource consumption*, which can be positive by reducing the use of materials (Fargnoli et al. 2019), water (Bressanelli et al. 2018), land (Firnkorn and Müller 2012), energy (Ingemarsdotter et al. 2019), or fuel (Lim et al. 2018). However, effects can also be negative, especially due to impaired longevity (B4), misuse (D1), a lack of lifecycle orientation in design (Matschewsky 2019), and the energy consumption of smart technologies (B2) (Liu et al. 2020). Moreover, the dimension includes *emissions and pollutants*, which can be reduced through reuse (B4) (Alcayaga et al. 2019; Li and Found 2017), product system substitution (B7) (Bonilla-Alicea et al. 2020), and an indirect effect resulting from a decrease in fuel or energy consumption (B2) (Haftor and Climent 2021). However, the effects on emissions and pollutants can also be negative. For example, a sharing system could increase transport through rebalancing (D2) (Bonilla-Alicea et al. 2020), leading to higher emissions. Finally, *waste* is essential in the ecological dimension, which can be addressed by preventing obsolescence through upgradability (B5) (Bressanelli et al. 2018) or optimizing manufacturing processes through smart technologies (A4) (Parida et al. 2019). In contrast, smart technologies can also increase waste by shortening product lifetime (B4) (Bridgens et al. 2019).

Finally, the social dimension includes human rights and equality, which are addressed, e.g., through broader access (C1) (Blüher et al. 2020) or the elimination of health risk for workers in the informal recycling sector in the Global South when minimizing obsolescence (B4) reduces e-waste in the Global North (Bridgens et al. 2019). The last aspect can be positive or negative depending on the outcome of eliminating jobs and substituting employment opportunities (B7). Hence, it also relates to *labor practices and safety*, such as reduced work accidents by optimizing processes (A4) (Parida et al. 2019). At the same time, new concerns about ergonomics come into play with digitalization (B7) (Kerin and Pham 2020). In addition, the social dimension includes product stewardship, which addresses the health and safety implications for the user, including injury prevention (Moreno et al. 2017), sudden breakdowns (Lim et al. 2018), proper medication (Chang et al. 2019), and healthy living (Valencia et al. 2015). It also includes sustainable behaviors of the user (C3), such as fuel-efficient driving (Haftor and Climent 2021). Moreover, product stewardship includes the negative impact of data security concerns (Moreno et al. 2017). Lastly, society refers to the impact on communities, such as road safety (Halstenberg et al. 2019), access to transportation (Bonilla-Alicea et al. 2020), and regional development (Parida et al. 2019).

4.3.4 A causal logic framework for impact design: specifying multi-causal pathways

In this section, we present our causal logic framework as a morphological box (Fig. 9). The box visualizes all of the design, causation, and impact options we identified in the literature. Note that the *cascades* of mechanisms, e.g., increased customer interaction (C2) leading to customer stewardship behavior (C3), are shown vertically within one type of mechanism (in the previous example, (C) the empowerment mechanisms). For an overview of the causal links, see Sect. 2 and the visualization in Fig. 1. However, other causal links are not visualized to maintain the readability and usability of the tool. For a detailed description of the mechanisms, please refer to Sect. 4.3.2. Managers can use this morphological box as an impact design tool for sustainable smart PSS. It serves as a toolkit to develop, challenge, and test logic models and the assumed relationships within multi-causal pathways. To do this, managers must first define and prioritize impact objectives. Second, they need to determine which BMPs give rise to the mechanisms that lead to the desired effects by formulating assumptions about these relations. Third, they need to test the hypothesized relationships, first hypothetically through stakeholder engagement, and later in practice using indicators for the mechanisms and effects.

4.3.5 Illustrating logic models and potential failure modes

In the following, we illustrate the use of the tool for constructing multi-causal pathways with different logics to show the importance of understanding relations and potential failure modes. We define a *failure mode* as a process by which BMPs, or the lack of them, cause unintended negative effects through a series of steps. We use the introduction of product sharing as an example. Figure 10a–c visualizes our discussion of logic model development in the style of Funnell and Rogers (2011).

The literature often oversimplifies PSS as inherently positive for the environment, especially for resource consumption (Barravecchia et al. 2021). Upon closer examination (see Fig. 10a first box), product sharing can result in product system substitution, enabling the intensified use mechanism (B3) (Kjaer et al. 2019; Tukker 2015). However, these assumed relations may not materialize. Matschewsky (2019) describes the case of a company that introduces product sharing for industrial equipment but without incorporating the BMP lifecycle orientation into design. Because design incentives are still focused on traditional product sales (i.e., low production costs rather than reduced lifecycle costs), poor component repairability fails to activate the resource mechanism and increase product longevity (B4), instead leading to reduced longevity and increased resource consumption (see Fig. 10a second box). Thus, the design fails to activate the relevant change in knowledge and behavior needed for the resource mechanism. This example highlights the need for an active lifecycle orientation in design to induce positive environmental effects through the resource mechanism. Only by aligning design incentives with the desired impacts can managers achieve this objective. Similarly, despite the importance of data sharing between stakeholders in sustainable smart PSS ecosystems, companies are still reluctant to share data internally and externally to improve control, optimization, and design for reuse and remanufacturing (Ingemarsdotter et al. 2020). Hence, the lack of the BMP of stakeholder co-creation hinders the mechanism of information exchange (A3) that could enable improved design (A5). While Li et al. (2021a, b) proposed a blockchain-enabled platform to enhance the credibility of information sharing along the value chain, future research could explore the antecedents of data sharing for reuse, remanufacturing, and recycling (Ingemarsdotter et al. 2020).

Beyond the lack of BMPs, other mechanisms can also undermine sustainability effects. Matschewsky (2019) outlines two issues driving the rebound and rebalancing mechanism (D2) (see Fig. 10b). First, the redesigning of products to reduce resource consumption in the use phase can lead to increased resource consumption in production. Therefore, to have a positive impact on resource use, the reduction



Fig. 10 a Constructing multi-causal pathways: the lack of BMPs. **b** Constructing multi-causal pathways: identifying trade-offs. **c** Constructing multi-causal pathways: inducing customer stewardship behavior

in the use phase must be greater than the increase in the production phase. Another frequently reported trade-off for smart technology BMPs for the (after)use phase is

the balance between the customer benefits and the increase in energy consumption and waste (Halstenberg et al. 2019). Avoiding this failure mode by design requires an early analysis of trade-offs between and within lifecycle stages. Second, due to the reduced costs of product sharing, the freed-up financial resources are invested elsewhere, consuming again resources. This rebound effect is, by nature, an unintended negative effect caused by an indirect mechanism, thus constituting a feedback loop. In the case of a rebound effect combined with a lack of lifecycle orientation (Matschewsky 2019), the induced increase in resource consumption constitutes a multi-causal effect. Similarly, the introduction of product sharing for bicycles can, as a parallel sequence, increase vehicle traffic due to rebalancing, increase fossil fuel consumption (direct effect) and CO₂ emissions (indirect effect). However, reduced costs (direct effect) might also facilitate broader access to transportation for the community (Bonilla-Alicea et al. 2020) as an indirect mechanism creating a positive societal impact. This example illustrates the importance of identifying the full multicausal pathway. Otherwise, interconnected parallel sequences, indirect mechanisms, and indirect effects may be overlooked. Moreover, it is pivotal for managers to determine a shared target impact to prioritize among various sustainability effects when trade-offs arise.

Activation of the careless customer behavior mechanism (D1) is another failure mode (see Fig. 10c). Careless customer behavior is driven by changed ownership and results in faster product wear and tear (reduced product longevity, B4) (Bridgens et al. 2019). For example, Fargnoli et al. (2018) reported that product sharing of medical devices required many extraordinary interventions due to inappropriate use. However, they observed that operational support by providing information and training reduces the number of maintenance interventions. The trainings facilitate increased customer interaction (C2), which cascades into customer stewardship behavior (C3). Therefore, to avoid the failure mode of careless customer behavior (D1), operational support is a BMP that can induce a change in user knowledge and behavior through a mechanism cascade of increased interaction and customer stewardship behavior.

In addition to operational support, the newly identified BMP behavioral support combined with smart BMPs offers potential to reverse the adverse mechanism of careless customer behavior (D1). Bressanelli et al. (2018) explored laundry product sharing combined with sensing and connectivity, data integration, and analytics. The case company monitors and analyzes users' consumption of electricity, water, and detergent. These insights (A2) are shared with the user (A3) to provide feedback on reducing these resources. This increased interaction (C2) constitutes operational support, providing the user with the necessary information for operational efficiency during the products' use (B2). In turn, a reduced fee constitutes the behavioral support that motivates customer stewardship behavior (C3), as it nudges the users to actually change their behavior through monetary rewards for the resulting resource savings. Thus, smart BMPs enable a cascade of information mechanisms. They generate customer and usage insights (A2) and facilitate information exchange (A3). Operational support provides feedback to the user through customer interaction (C2), thus offering information to change behavior, while behavioral support actually induces customer stewardship behavior (C3). This shows the potential

of behavioral and operational support based on multiple BMPs to create impact by aligning incentives between the provider and the customer. However, the effect of multi-causal pathways may vary depending on the user's response (Funnell and Rogers 2011, pp. 176–179). For example, a (sustainable) smart PSS might reduce access to digitally unsophisticated consumers while increasing customer feedback, usage efficiency, and customer empowerment (Tunn et al. 2020). In addition, some consumers may change their behavior based on the information provided by the operational support, some based on the incentives provided by the behavioral support, and some may not change their behavior at all. Therefore, innovators should analyze different user groups and consider developing a logic model tailored to their different behaviors.

Another opportunity to avoid careless customer behavior is through contract design. Customers may enter into optimized result contracts when they perceive products as high maintenance or if they intentionally misuse the product and drive up maintenance costs covered by the contract (Parida et al. 2019). This can have negative effects on product longevity (B4) and, thus, on resource use. Although contract design is critical for aligning provider and customer incentives and preventing negative customer behavior, we have not included contract design and the value capture dimension in our framework. To reduce complexity, we focus only on the value proposition and refer to future research to fill this gap.

In summary, aligning incentives internally through the adoption of sustainability-oriented BMPs and externally through the design of operational and behavioral support is key to aligning profits with social and environmental impacts. Likewise, adhering to the target impact when trade-offs arise and considering indirect mechanisms and effects are key to specifying multi-causal pathways holistically. Thus, designing for impact requires astute orchestration of the individual BMPs and individual mechanism or cascades of mechanisms throughout the lifecycle of sustainable smart PSS.

5 Discussion: research propositions and managerial questions for impact design

Based on the theory of change, we conceptualize a three-step causal logic framework that opens the black box between the design and impact of sustainable smart PSS. With our SLR, we shed light on the link between the two, causation, and identify 17 individual mechanisms grouped into four types of mechanisms. To describe the causation processes, we introduce the term *multi-causal pathway*, emphasizing possible non-linearity and multi-causality. We illustrate our causal logic framework with examples from our SLR, highlighting potential failure modes and the importance of user behavior in achieving the innovator's target impact.

In the following, we first develop research propositions on multi-causal pathways, failure modes, and user behavior. For each of these, we develop two propositions. The first incorporates our learnings specific to the impact of sustainable smart PSS, and draws attention to the theory of change as a valuable perspective. The second

relates these learnings to general sustainability management discussions, making our research relevant to a broader audience. Beyond these academic contributions, we outline managerial contributions by providing guiding questions for impact design.

5.1 Academic contribution: research propositions

Similar to our findings, Teece (2018) described how the rise of Uber made transportation readily available and reduced the need for users to own cars, thereby stimulating demand and saving capital. In our framework, this is reflected in the activation of the mechanisms of product system substitution and intensified use, resulting in lower costs and facilitating broader access. However, this might only portray a small part of the entire multi-causal pathway, as there could be adverse mechanisms that torpedo the positive economic and social effects. For this reason, the simple classification of product sharing, which is recognized as a way to reduce the need to manufacture the product (Kjaer et al. 2019), does not allow conclusions to be drawn about how or what impacts are actually generated. There are competing forces at work, and only after a detailed evaluation can one conclude whether the intended effect actually materializes or remains an intention. In essence, this requires a granular analysis of the mechanisms and their respective impacts that are set in motion by design. Complex business models can be analyzed by specifying multi-causal pathways to create an overall picture of sustainable smart PSS. Multiple BMPs work together to trigger a single mechanism or cascades of mechanisms. In addition to these direct mechanisms, indirect mechanisms are induced by TBL effects. Thus, there are horizontal relations (causal links and feedback loops between design, causation, and impact) and vertical relations (cascades of mechanisms) in our framework.

Although there are many examples of negative impacts in practice, there is, generally, little research on the negative effects of (sustainable) smart PSS. Moreover, research on the positive impacts tends to focus on potentials rather than actual effects. For this reason, the BMPs and the mechanisms they activate deserve more attention. Therefore, we propose:

Proposition 1a: Business model properties do not lead directly to TBL effects, but first translate into mechanisms that lead to multi-causal pathways.

We apply the theory of change (Carman 2010; OECD 2002; Wagner et al. 2021) to understand how sustainable smart PSS (design) create sustainability effects (impact), conceptualizing our causal logic framework (see Fig. 1). The initial design step focuses on how innovators define the BMPs of sustainable smart PSS. In the causation step, a change in resources, knowledge, values, or behaviors occurs. Finally, in the impact step, sustainability effects occur. Based on these three steps, logic models serve to determine a target impact, and to identify and test the assumptions behind the multi-causal pathways. We can transfer the theory of change's approach of developing a logic model as well as our derived three steps of design, causation, and impact as a universal perspective that can be applied to every sustainability-oriented innovation. To do so, managers need to build consensus on the target impact among relevant stakeholders. Next, they can determine which design characteristics lead to the desired impact by formulating assumptions. Finally, they

can test the plausibility of these assumptions in two ways: before implementation, through stakeholder dialogue, and after implementation, by measuring appropriate indicators of mechanisms and effects. This relates to the current discussion on the necessary dynamic capabilities for developing sustainability-oriented innovation (Bocken and Geradts 2020; Teece 2018), including, e.g., collaborative innovation and organizational flexibility (Santa-Maria et al. 2022; Witschel et al. 2019). While the individual BMPs and mechanisms we identified may require adaptation, we suggest that the causal logic perspective summarized in Fig. 1 can be valuable for impact questions in sustainability management that do not only relate to business model design. Organizational design, supply networks, and reporting systems are also areas where design characteristics must be placed in the context of multi-causal pathways and their barriers to target impact. We thus posit:

Proposition 1b: Every sustainability-oriented innovation achieves impact through a multi-causal pathway consisting of a design, causation, and impact step.

While achieving a target impact requires measurement to evaluate whether the intended effect is realized, the reason for missing the objective may originate from the design and causation steps. Therefore, it is crucial to understand relations and potential failure modes, which we define as a process where (missing) BMPs cause unintended negative effects through a series of steps. They thus describe missing or undesirable links within multi-causal pathways. One potential cause is the lack of sustainability-oriented BMPs, which results in the failure to activate a particular mechanism. As described earlier, the introduction of product sharing might still fail to activate resource mechanisms if the design does not favor product longevity (Matschewsky 2019). Likewise, the activation of the information mechanisms might be hindered by a lack of stakeholder co-creation and their willingness to share information (Ingemarsdotter et al. 2020). In addition to failure modes based on non-activation, another cause for not achieving the target impact are adverse mechanisms, including adverse customer behavior and rebound and rebalancing effects. Identifying where such failure modes might occur and how to avoid them is thus important for the actual impact creation. Therefore, we assert:

Proposition 2a: The core of failure modes lies in the non-activation of desired mechanisms or the unintended activation of undesired mechanisms during causation.

Evaluating the impact of sustainable smart PSS requires indicators not only of the actual impact, but also of the activation of mechanisms. An important failure mode that hinders the mechanism of product longevity is the lack of a lifecycle orientation as a BMP in design, which ultimately results in negative environmental effects (Matschewsky 2019). By measuring only the environmental impacts, it may be difficult to derive improvement measures. This is where causal indicators can help to monitor these causal links. After all, it is during causation that it becomes clear whether the causal links have actually been activated, linking BMPs, mechanisms, and impacts through the if–then logic. Therefore, critical link indicators contribute to a better understanding of how the mechanisms generate impacts in the causation step and are needed to understand and manage multi-causal pathways. Thus, we show the link to the impact discussion in sustainability management (Braig and Edinger-Schons 2020; Trautwein 2021). Given the scope of this study, we leave the further

development of these indicators to others, and refer to the active debate on the development of indicators for impact measurement (Kühnen and Hahn 2017; Trautwein 2021). Currently, many companies measure environmental impacts by relying on "rules of thumb" (i.e., on internal policies, guidelines, and estimations) and report measurement barriers, including lack of data and uncertainty due to many assumptions in the innovation process (Das et al. 2022). Our causal logic framework serves as an easy entry point for measurement, as it is an intuitive tool that requires managers to specify and test the underlying assumptions. We thus posit:

Proposition 2b: The design and management of sustainable smart PSS benefit from specific indicators that measure not only the final impact, but also the performance of mechanisms in the causation step.

Regarding impact creation, researchers and practitioners need to consider the change in relationships that sustainable smart PSS bring about. Customer behavior is a critical determinant of sustainability impact because the use phase largely determines sustainability effects (Haftor and Climent 2021; Reim et al. 2018; Valencia et al. 2015). However, the mechanisms of customer stewardship behavior and adverse customer behavior have not yet received the scholarly attention they deserve. Perceiving the consumer as a social and learning being can help achieve the target impact (Hankammer et al. 2021). For example, innovators can reflect on how to enable customer stewardship behavior during the design step. We return to this point in Sect. 5.2 addressing our managerial implications. The newly identified BMP of behavioral support can help promote stewardship by nudging consumers toward more sustainable behaviors through rewards and incentives. To address adverse customer behavior, building on the BMP of operational support, providers can use smart technologies to monitor behavior and provide feedback on how to contribute to sustainability (Bressanelli et al. 2018). In addition, helpful measures include building intimate customer relationships and building a strong customer community (Schaefers et al. 2016), that is, using the mechanism of increased customer interaction. Thus, the monitoring and feedback provided by operational support helps to build appropriate competencies, and behavioral support can address the emotional needs of consumers. Further research is needed to understand how creating motivation can play a role in supporting and nudging sustainable smart PSS users to perform a specific sustainable behavior. We thus posit:

Proposition 3a: Inducing behavior toward sustainability requires both operational support by building competencies and behavioral support by creating motivation.

Another critical element that influences human behavior is value capture. Given the link between the PSS pricing logic and customer behavior (Reim et al. 2015), it is essential to understand the value capture architecture and its sustainability implications to mitigate the adverse customer behavior mechanism. Although the pricing logic might not fundamentally change the business model itself, it changes the incentive structures (Teece 2018) and, therefore, human behavior. As a result, the sustainability impact might vary depending on the pricing logic. For example, the car-sharing provider MILES Mobility in Germany offers payment based on the distance driven (MILES Mobility 2021), whereas the German car-sharing provider WeShare charges its customers based on the minutes driven (WeShare 2021). This difference in the unit of payment is likely to have a critical impact on consumers' driving behavior as the time-based pricing motivates fast and potentially unsafe driving. Therefore, we urge scholars to go beyond the value proposition dimension and dedicate efforts to exploring the architecture of value capture within PSS and its impact on the TBL. Research has discussed the continuous alignment of value creation and value capture as a key determinant for successful service-driven business model innovation and calls for academics to further explore failures in the innovation process, as well as the appropriate alignment for different BMPs (Sjödin et al. 2020). Therefore, we state:

Proposition 3b: Value capture decisions can translate either into empowerment mechanisms or into adverse mechanisms and, therefore, need to be considered carefully.

In conclusion, our causal logic framework extends current research on the sustainability impact of (sustainable) smart PSS. For example, in a study assessing the sustainability effects of digital sharing systems, the authors identified three effects, namely, the "optimization effect" addressing the intensified use enabled through sharing, the "rebound effect," and the "induction effect" related to complementary resource consumption, such as the occupation of roads by car-sharing (Pouri and Hilty 2020). While our framework reflects these as mechanisms, it provides a more comprehensive view and distinguishes three phases to holistically present multicausal pathways of sustainable smart PSS. In contrast to previous research (Allen Hu et al. 2012; Schöggl et al. 2017), this impact approach allows for a more nuanced sustainability assessment of sustainable smart PSS, by distinguishing between the actual (dis)value created and the mechanisms that lead to the respective effect. By distilling a causal logic framework for the impact design of sustainable smart PSS, we contribute toward a conceptual synthesis for understanding the effects caused by (sustainable) smart PSS.

5.2 Managerial implications: guiding questions for impact design

To create impactful, sustainable smart PSS, innovators need to consider multi-causal pathways. The mechanisms activated by BMPs produce (un)intended economic, ecological, and social effects. If these outcomes are inadequate, countermeasures can be designed early to achieve the desired impact. To emphasize the importance of the causation step, our morphological box (see Fig. 9) can serve as a tool for managers to develop a logic model of multi-causal pathways showing all critical links within their respective sustainable smart PSS business model. In this way, it can help to activate the mechanisms needed to bring about desired sustainability effects in the innovation process of sustainable smart PSS. As additional guidance, we developed a checklist of guiding questions for impact design in the innovation process of sustainable smart PSS in Table 3.

In doing so, we highlight the importance of the design step in achieving the desired impact. As noted above, failure modes can result from the lack of sustain-ability-oriented BMPs. This contrasts with previous research suggesting that the design logic for PSS automatically favors retaining product ownership, assessing

Checklist: guiding questions for impact design						
Торіс	Guiding questions					
Developing a theory of change (see Funnell and Rogers 2011, pp. 95–148)	 Who should be involved? What should be their role? What is your approach to develop the theory? How might workshops and interviews be used? How much effort and resources should be invested? When is it time to revisit the theory? 					
Developing a logic model (see our section on the qualitative thematic results)	 What is the target impact? Which are the business model properties you combine to achieve the target impact? Which mechanisms are activated by the combination of business model properties? Which are not? How can you link your design, causation, and impact steps through an if-then logic to map multi-causal pathways? How do you prevent the adverse mechanisms? How do you foster the empowerment mechanisms? 					
Refining and testing a logic model (see Funnell and Rogers 2011, pp. 277–292)	 Which critical links determine your impact? Did you focus on the critical links and potential failure modes? Did you indicate a direction of expected change? What are the specific indicators for the critical links? How do you measure the sustainability effects? How do you measure the activation of mechanisms? 					

Table 3 Checklist to guide impact design

the total cost of ownership, and designing for circularity (Tietze and Hansen 2013), thereby internalizing externalities along the product lifecycle (Tukker 2015). Our findings highlight that this integration requires the introduction of a systematic understanding of stakeholder perspectives, lifecycle costs, value creation, and value capture. According to Teece (2018), not only must all BMPs and dimensions be internally aligned and coherent to be mutually reinforcing but so must the organization's strategy and culture. As outlined above, dynamic capabilities are of paramount importance in this context (Bocken and Geradts 2020; Witschel et al. 2019). Thus, designing for impact requires an innovation process aligned with the impact logic. Our guiding questions (see Table 3) provide a structure for considering the relevant stakeholders and BMPs during the innovation process. First, the questions for developing a theory of change (Funnell and Rogers 2011, pp. 95–148) check the correct set-up for the innovation process, such as the participation of relevant stakeholders. Second, the logic model development questions help managers rethink and redirect the design of BMPs. They also challenge whether all relevant mechanisms are activated or whether failure modes impede impact, thus identifying unintended negative effects. Finally, the questions for refining and testing the logic model support the accuracy of the model and the assessment of the desired impact, thus contributing to better accountability of sustainability-oriented innovations (Funnell and Rogers 2011, pp. 277–292). The testing of the model can be based on ex ante stakeholder feedback and the ex post assessment of specific indicators. Sustainable smart PSS are complex systems. However, innovators should focus on the critical links and potential failure modes to avoid showing too many links and feedback loops. Each box and arrow should be meaningful and show a sequential progression; anything else can be removed. This creates a readable and robust logic model and helps measure what is meaningful.

5.3 Limitations

While we contribute to a holistic understanding of the impact of smart PSS, our study has limitations. To start with, the identification of articles depended on the choice of databases, the search terms used, and the search string application. Given the contingency of these parameters, it is possible that some papers corresponding to the research focus were not discovered. Furthermore, although our SLR broadly covered academic literature from different research fields, the characteristics of sustainable smart PSS, the mechanisms, and the TBL effects are only vaguely defined within them. Clear-cut definitions are missing. Therefore, interpretation by the authors was required to make sense of the data. This exacerbated the interpretation bias of our study, which results from the fact that the thematic analysis builds on a qualitative interpretation of the identified literature. In terms of reliability, further research is needed to test the developed causal logic framework by applying it to a large number of cases with different design characteristics. This will ascertain the applicability and generalizability of our results and concerns Proposition 1b.

Furthermore, our framework only allows for a qualitative assessment and does not support quantitative measurement of sustainability effects (see Proposition 2b). However, in developing our framework, we analyzed several studies on LCA, a quantitative approach to impact. There are many difficulties in applying LCA to PSS and smart technologies (Kjaer et al. 2016). Due to complexity, studies mostly do not consider rebound effects and changes in consumption caused by PSS (van Loon et al. 2021). Especially in design, the necessary information is often not available, resulting in high uncertainties and the need for assumptions (van der Giesen et al. 2020). However, it is equally important to consider the negative effects that may arise. The strength of our approach is that it supports the identification and testing of assumptions. It considers not only sustainability gains (information, resource, empowerment mechanisms), but also sustainability burdens (adverse mechanism). Removing these burdens can be just as important as focusing on impacts that can be discarded. This reflects the notion of value creation and disvalue mitigation (Beckmann and Schaltegger 2021). In this context, our framework provides a structure for identifying relevant mechanisms and causal links, which can serve as a guide to better address these challenging questions before conducting an LCA.

5.4 Avenues for future research

The limitations of our framework and the propositions we developed give rise to many avenues for future research. For example, academics can apply the theory of change and our three-step causal logic perspective to sustainability-oriented innovation and other impact issues in sustainability management. In addition, future studies can develop indicators for multi-causal pathways, including the mechanisms and the impacts created. In addition to this empirical descriptive tool, researchers could aim to develop normative approaches that support managers in making the right decisions, as current frameworks are based on subjective preferences (Song et al. 2021). Finally, we support the call to further explore failures in the innovation process, and the appropriate alignment between value creation and value capture for different BMP combinations (Sjödin et al. 2020).

The results of our SLR also highlight blind spots. First, our review found that sustainable smart PSS are under-researched from a theoretical perspective. This is a crucial gap, as sustainable smart PSS change the role of actors and the interactions between them. From a sustainability perspective, theories that seem particularly suitable include institutional logics (Friedland and Alford 1991) for addressing consumer expectations regarding offerings, agency theory (Eisenhardt 1989) to analyze adverse consumer behavior, transaction cost theory (Williamson 1979) for scrutinizing the interaction between consumer and provider, and stakeholder theory (Freeman and McVea 2001) for shedding light on the different stakeholders involved, their roles and contributions. Similarly, dynamic capabilities offer a valuable perspective for understanding a firm's ability to transform the innovation process in a way that aligns the targeted impact logic with the culture and structure of the innovation logic (Teece 2018; Witschel et al. 2019). Second, there are three gaps in academic literature on the impacts of sustainable smart PSS: a lack of research on the social dimension, a lack of literature on negative impacts, and a tendency to report potentials rather than measure impacts. However, sustainable smart PSS offer significant opportunities for social impacts, such as product stewardship that supports consumer health (Chang et al. 2019). At the same time, data surveillance, which could be a potential human rights issue, is not discussed in the literature. Therefore, the social impact of sustainable smart PSS requires further investigation. Moreover, researchers can set out to quantify the value and disvalue created by sustainable smart PSS, including all dimensions, especially the social dimension.

6 Conclusion

To understand the impact of smart PSS holistically, we take a two-pronged approach. First, we use the theory of change to conceptualize how sustainable smart PSS lead to impact. We develop our causal logic framework, which consists of design, causation, and impact. We identify BMPs of sustainable smart PSS as design characteristics and categorize the impacts based on the TBL. We introduce the term *multi-causal pathway* to describe the causation processes, emphasizing the possibility of non-linearity and multi-causality. Second, we conduct an SLR to

investigate the mechanisms linking design and impact. Based on a content analysis of 63 publications, we identify 17 individual mechanisms and group them into four types: information, resource, empowerment, and adverse mechanisms.

In doing so, we link intersecting research perspectives and concepts, including sustainability management, servitization, digitalization, and innovation. In our causal logic framework, we distinguish between sustainability as a design principle that specifies the target function of the innovation (Dzhengiz and Hockerts 2022) and sustainability as an outcome that represents the impact function. By distinguishing design, causation, and impact and identifying individual characteristics and mechanisms, our framework aligns the literature on sustainability, smart technologies, and PSS, thus contributing to greater conceptual clarity between the research fields. Based on our SLR, we map the existing literature and identify future research directions. As a conceptual synthesis, our research propositions draw academic attention to the theory of change as a valuable perspective for understanding the creation of sustainable impact. In addition, the propositions link to current discussions in sustainability management research. Although the specific framework is not a "one size fits all" strategy, the non-linear, multicausal three-step logic (Fig. 1) can be applied to general sustainability management. As a general insight, we suggest that this logic can be valuable for impact issues related not only to business model design but also organizational design, supply networks, reporting systems, and others, where design principles need to be placed in the context of multi-causal pathways and their barriers to desired impact.

As a managerial contribution, our morphological box (Fig. 9) provides managers with a toolkit for developing their own impact-oriented logic model. By visualizing the BMPs, mechanisms, and potential positive and negative TBL effects, a structure emerges for creating a system map of sustainable smart PSS that depicts all the critical causal links of the impact logic. Emphasizing the importance of the causation step, this can serve as a guide to understanding and activating the mechanisms needed to bring about the desired sustainability effects in the innovation process. To realize the opportunities offered by sustainable smart PSS, the morphological box can help innovators rethink and align the design of BMPs based on the innovation goal, i.e., the target impact. In addition, we generate guiding questions for impact design (Table 3) as a checklist to challenge the setup for creating a theory of change, identifying and activating multi-causal pathways, and the refining and testing of the logic model. It asks whether all relevant mechanisms are activated or whether failure modes impede the target impact, thus identifying unintended negative effects. Therefore, the checklist helps innovators to actively design sustainable smart PSS to promote positive and avoid negative TBL impacts.

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Data availability A data extraction sheet can be obtained from the authors.

Declarations

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