

Article

Designing Environmentally Sustainable Product–Service Systems for Smart Mobile Devices: A Conceptual Framework and Archetypes

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Abstract

Smart Mobile Devices (SMD)—including hardware devices, such as smartphones, tablets, and wearables; the software systems that animate them; and the data-communication infrastructure that connects them—pose increasing sustainability challenges due to their short lifespans, high resource demands, and growing e-waste. While Sustainable Product–Service Systems (S.PSS) have been applied in various sectors to support environmental goals, limited research has addressed their application in the context of SMD. This study aims to explore how S.PSS can be tailored to support sustainability in the SMD sector. For that, it combines a literature review with a multiple-case analysis of seventeen commercial offerings to develop a conceptual framework refined through six expert interviews. Cases were coded using the classical PSS typology and other sector-specific criteria and subsequently clustered in a polarity diagram to identify designable patterns, underpinning the conceptual framework. The study contributes an S.PSS-SMD framework comprising a sector-tailored classification and sixteen archetypal models, operationalized in an archetypal map with potential opportunities. Theoretically, the study offers a sector-grounded operationalization that extends S.PSS design theory to digital product–service ecosystems. It provides a strategic decision aid for designing business models, service bundles, stakeholder roles, and lifecycle responsibilities to pursue win–win environmental and economic sustainability.

Keywords: Product-Service Systems; Smart Mobile Devices; design for sustainability; archetypal map



Academic Editor: Abdul-Sattar Nizami

Received: 14 July 2025

Revised: 15 September 2025

Accepted: 19 September 2025

Published: 23 September 2025

Citation: Su, H.; Petrecca, A.C.C.; Vezzoli, C. Designing Environmentally Sustainable Product–Service Systems for Smart Mobile Devices: A Conceptual Framework and Archetypes. *Sustainability* **2025**, *17*, 8524. <https://doi.org/10.3390/su17198524>

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1. Introduction

Smart Mobile Devices (SMD) and their systems can encompass personal and connected gadgets, their embedded and cloud software, and the infrastructures that support them, including data center resources, cables, and energy [1]. They facilitate connectivity between billions of end users and the internet. However, while offering many benefits by disrupting and facilitating information and communication, they also pose risks. The widespread adoption of SMD has had significant environmental consequences [2]. In 2022, the number of active smartphones reached 8.891 billion [3], surpassing the global population of 7.9 billion [4]. The data center electricity global consumption is estimated to be between 240 and 340 terawatt-hours, accounting for 1–1.3% of the global final electricity demand, and growing by 20–40% annually [5]. It is predicted that SMD will account for around 63% of all internet traffic by 2025 [6] and produce greenhouse gas emissions that will exceed those from data centers and telecommunications networks worldwide combined [7].

A considerable number of scholars who employ Life Cycle Assessment (LCA), a widespread methodology for investigating the environmental impact of products, concur that the upstream processes (raw material acquisition and any transformation to make them usable in production) and production phases have the greatest environmental impact [8,9], accounting for 70% of the total SMD lifecycle impact [10,11]. Extending the lifespan of devices and reducing the demand for new production are therefore crucial strategies for minimizing environmental impacts [8]. However, the average lifespan of smart mobile devices (SMD) is only 2–3 years [12], primarily due to unsustainable supply patterns characterized by technical obsolescence [13] and excessive production [14], making it necessary to rethink the way smartphones are consumed [15]. This is a key reason for the European Union's prioritization of the electronics and ICT (Information Communication Technology) sectors in its sustainability policies [16], making SMD a central focus in any credible narrative of a sustainable digital economy.

A Sustainable Product-Service System (S.PSS) is a business model in which the producer retains ownership and/or responsibility for its products throughout their lifecycle [17]. This approach has been recognized as a promising way of achieving environmental and economic sustainability, as it has the potential to add value to system lifecycles [18]. It can decouple revenue from the number of devices produced and provide economic incentives for producers to design devices with a longer lifespan [8,19], providing more sustainable solutions. This is because, when product ownership or life cycle responsibilities remain with the producer/provider, extending product life or recycling materials allows the provider to avoid the raw material, production, distribution, and disposal costs associated with manufacturing and disposing of additional devices, increasing profit margins while reducing environmental impact. Although few companies in the SMD sector have adopted S.PSS, most initiatives have struggled to create economic incentives for designing and manufacturing durable devices because original device manufacturers are rarely positioned as central stakeholders, such as Grover, which merely leases refurbished phones produced by other brands. Fairphone attempted to overcome this misalignment through its "Fairphone-as-a-Service" pilot, which integrated in-house design and production with a subscription-based service model [20]. Despite its innovative structure, the pilot was recently suspended due to certain issues, e.g., user preferences for device customization and related privacy concerns [21], thereby exposing barriers that need to be addressed when designing S.PSS models applied to the SMD sector.

The general knowledge base in S.PSS has been maturing—e.g., Tukker's [22] typology of Product-Service System (PSS) and Vezzoli et al.'s [23] comprehensive design methodologies (including design scenarios, tools, and guidelines, etc.). However, there are no S.PSS studies that adequately and systematically capture the specificities of the SMD ecosystem [24], where hardware–software–connectivity are coupled, and short life cycles are common. Therefore, existing S.PSS studies offer limited guidance for SMD designers and providers who must configure concrete bundles (ownership, services, performance responsibilities) under sector-specific constraints such as firmware support, data connection, and protection. Given that design decisions strongly influence environmental performance already in the early phases [16], advancing sustainability in the SMD industry requires more carefully tailored S.PSS design knowledge that operationalizes general principles for this sector.

Motivated by this gap, two research questions were formulated: (1) What are the key characteristics of S.PSS applied to the SMD sector? (2) How can S.PSS be tailored to support sustainability in the SMD sector by developing/designing possible S.PSS-SMD offer models? The present study develops an SMD-specific S.PSS design framework comprising a set of S.PSS-SMD characteristics (addressing RQ1), an archetypal map with sixteen

offer models (addressing RQ2), and identification of future opportunities for sustainable business innovation in the SMD sector. From the SMD perspective, it introduces S.PSS as a strategic lever to extend device lifetimes, intensify use, etc. From the S.PSS perspective, it provides a focused operationalization of S.PSS theory in a complex digital ecosystem, thereby enriching design-for-sustainability research with sector-grounded constructs.

The article is structured as follows: introduction (Section 1); Section 2 presents the S.PSS and SMD-relevant literature background; Section 3 outlines the research methodology; Section 4 describes the S.PSS–SMD characteristics, which form the basics for the archetypal map; Sections 5 and 6 introduce the structuring process and details of the archetypal map, respectively; Section 7 discusses implications; and Section 8 concludes, outlining limitations and future research.

2. S.PSS and SMD Parallels

2.1. S.PSS Types and Existing SMD Offerings

Product-Service System (PSS) is a business model that shifts the centrality of product commercialization to the provision of a mix of products with services that meet specific customer demands, also called ‘unit of satisfaction’ [25]. When the provider retains the ownership of the product or is responsible for its lifecycle (sometimes described as moving from ownership to access or performance economies), the value is detached from the consumption of material resources [26]. In this case, the PSS is considered a win-win opportunity, beneficial for the three dimensions of sustainability (environmental, socio-ethical, and economic), therefore becoming a sustainable PSS, or S.PSS. Hence, it develops the provider’s interest in improving the environmental sustainability of its products and services, as well as reducing acquisition and/or maintenance costs for customers, providing differentiation of this offer in the market [23]. Early foundational work established the PSS concept as a strategy to deliberately design stakeholder configurations for leveraging sustainable benefits, e.g., companies can profit from the use of products and their efficiency rather than selling more units [26–29], and the classic typology of product-oriented, use-oriented, and result-oriented systems [25,30]. In product-oriented models, the provider sells its products and adds value through services that support their lifecycle (e.g., maintenance contracts, take-back programs). In a use-oriented model, the provider retains ownership of the product, and the customer pays for its use or availability (e.g., leasing, rental, or sharing). Finally, in result-oriented models, customers purchase a specific outcome. The responsibility rests with the provider, who uses the product-service mix to deliver this outcome.

Despite a limited number of studies on SMD and its systems [31], there is a growing consensus that novel consumption and business models such as S.PSS are essential to enhancing sustainability in the sector [23,32–34]. In fact, the development of offer models for SMD has led to a variety of new concepts within academia and the sector that can have certain parallels to S.PSS, such as carrier combined offers, or service bundling [35,36], SMD leasing [37,38], subscription services [20], upgradable PSS [39], pay-per-service unit, communication-as-a-service (CaaS) [24], product-as-a-service (PaaS) [33], etc. These emerging models can be placed under the idea of servitization, wherein SMD are offered not merely as standalone products but as integrated services or product-service hybrids [40]. Although digital technology-based solutions are mostly service-oriented, the perspectives of the S.PSS can enhance design strategies towards sustainability [31,41]. The growing policy emphasis on sustainability supports the development of S.PSS for SMD, especially taking advantage of SMD qualities that integrate its telecommunications services and other structures [42].

Therefore, based on the existing literature on S.PSS and a first approach to existing offers, it is possible to draw some parallels to the Tukker's types of PSS with SMD. Certain services can contribute significantly to extending product lifespans, as proposed in the product-oriented type of S.PSS [25]. In such models, services are bundled with products, focusing on supporting the use phase through maintenance, repair, or upgrade options [22]. Many SMD manufacturers and retailers already offer after-sales services aligned with this approach. For example, Samsung provides extended warranties and insurance plans that cover repairs or replacements within specified periods, reducing the cost barrier for users and encouraging them to maintain rather than discard devices. Trade-in services are also common. Major manufacturers (e.g., Apple, Samsung, Google, etc.) and network operators (e.g., Vodafone, TIM, etc.) incentivize users to return old phones in exchange for credit toward new purchases. While these may encourage new acquisitions, they also facilitate reverse logistics for reuse or recycling. Since consumers acquire the devices, Schneider et al. [19] propose combining PSS with modular design to ease component replacement or upgrades, thereby supporting longevity. Companies like Fairphone and Shiftphone exemplify this with self-repair tutorials and accessible spare parts. Additionally, some smartphone offerings incorporate telecommunications service contracts (e.g., O₂'s Refresh Plan). Although ownership typically remains with the customer, these service elements still contribute to a more sustainable model, resonating with the product-oriented S.PSS framework.

Use-oriented type is reflected in emerging SMD offerings where ownership remains with the provider, and consumers or enterprises access devices through leasing or subscription models [22]. These arrangements, such as 'Fairphone Easy' and Apple's proposed 'Upgrade Program', shift the focus from ownership to usage, enabling regular upgrades while promoting circular economy practices through the return, refurbishment, and resale of devices. Companies like Grover, Raylo, and Telia further exemplify this approach by offering rental or leasing services bundled with insurance, technical support, and upgrade options—often categorized as Device-as-a-Service (DaaS). Enterprise-focused providers like Everphone supply subscription-based device pools that include maintenance, replacements, and end-of-life processing, aiming to maximize use and ensure sustainable disposal. Jattke et al. [8] highlights the potential of such leasing models to reduce production and material requirements while extending product lifespans, though outcomes depend on contingent factors such as logistics and user behavior. These S.PSS models not only provide affordable access to up-to-date technology [43,44] but also enable firms to differentiate their offerings, stabilize revenue, reduce costs, gain competitive advantages, and collect product performance data [45].

Finally, in the case of the result-oriented type, the comparison is quite complex since a smart device's multifunctionality, due to its embedded software system and other digital services, surpasses its specific functional outcomes, providing results related to other services beyond communication. Nevertheless, S.PSS result-oriented types in relation to SMD can be seen when users pay for communication and information capabilities instead of equipment use or purchase. [24] discussed the feasibility of the Communication-as-a-Service (CaaS) model as an integrated solution incorporated into Business-to-Business (B2B) contexts. Service providers like the Everphone offer services that include device provision and its management during the contract period—backend upgrades, hardware replacements, recycling, and telecommunications services through partnerships with network providers. This resembles other result-oriented S.PSS offers involving equipment such as printing-as-a-service (e.g., Xerox 'Partner Print Services'), where customers pay per printed page, and the provider manages the printer and other resources. In Business to Customer (B2C) contexts, users can rent local smartphones and short-term network

plans for brief periods, typically for business or personal travel, paying for communication services in a short period (e.g., TravelWiFi, Hip Mobility). Finally, certain social projects involve sharing tablets or phones within organizations as mediums to provide results such as education. Such as ‘Libraries Without Borders’, which deploys connected tablets and digital resources in underserved European communities through its ‘Ideas Box’ program, or ‘Digital Schools of Europe’, which provides tablets and educational apps to students in rural and remote areas. These offers place the digital and dematerialization of services paradigm where physical smartphones are abstracted, directing users to concentrate on the ultimate outcome of communication as a seamless/frictionless medium.

These similarities of the existing offers to S.PSS point to possible patterns for the formation of archetypes that can be used to address the design of S.PSS offers applied to SMD offers. Nevertheless, it is important to acknowledge that consumers often exhibit hesitation towards adopting S.PSS applied to SMD, even when economic benefits or environmental attitudes are identifiable [46–49]. Lannoy et al. [24] acknowledged an appeal close to S.PSS for SMD in corporate scenarios. While certain drivers and barriers, such as financial considerations, appear universal, others, like usage duration or social establishments, seem dependent on context for users [21].

2.2. S.PSS User Empowerment and Value Co-Creation in SMD Contexts

According to Schneider et al. [19], while S.PSS can support sustainable outcomes by relying on manufacturers and service providers to enhance product durability, it is insufficient to overcome the social drivers/challenges of contemporary consumer culture. If end-users can be encouraged to invest time or money in maintaining or refurbishing products instead of replacing malfunctioning ones, the win-win potential of S.PSS could be significantly enhanced [19]. For example, this behavioral engagement becomes particularly relevant when considering the role of product ownership in SMD. Valencia et al. [50] divides Smart PSS ownership into two configurations. In the first, ownership of the tangible product—devices in systems (e.g., Kindle), is transferred to the consumer, who becomes responsible for maintaining the product, including installing software updates to ensure proper functionality. This ownership grants users ongoing access to services, though service access may still be governed by conditions such as subscription fees. In the second configuration, ownership is retained by the provider (e.g., Green Wheels), where the service provider maintains responsibility for product upkeep and users interact with the system through temporary or time-bound access, with less or no responsibility for the device’s integrity. These distinctions in ownership influence the degree of user involvement and the potential for sustainable behaviors, highlighting the importance of aligning business models with both environmental objectives and user engagement strategies.

In this sense the provision of services becomes essential to prolonging the life of devices. At this point, Distributed Economy (DE) frameworks can support S.PSS offers by providing the complex network of services that this kind of offer may require [51]. DE can be defined as an economic system comprised of interconnected autonomous productive units established near or by its final customers (prosumers) to provide goods and services [52], transferring control of crucial activities towards or by the end-user, such as production, maintenance, and repair [53]. Although a completely distributed manufacturing model may not be reachable, given that the SMD industry requires specific, rare resources and highly specialized knowledge, consumer behavior is viewed as a key factor in increasing the sustainability value of the S.PSS model [32]. If business models can be designed to actively encourage and support consumers in performing environmentally beneficial actions—such as extending product lifespans—this would further strengthen the role of business models in sustainable product use [21,54,55].

According to Pialot et al. [39], consumers may prefer full-service packages provided by technicians to avoid personal effort. However, an industry expert and consumer survey from Lannoy et al. [24] suggests that user-driven actions may be more appealing than full-service models. These user actions can make problem-solving more accessible and cost-effective. Moreover, because of the time and effort invested, consumers may develop a stronger attachment to their devices, increasing the likelihood of long-term use. In fact, a recent GSMA industry survey of global consumers finds that 70% are willing to pay more or otherwise act in support of sustainable mobile-device practices, signaling rising sustainability awareness in the SMD sector [42]. Additionally, ref. [12] points to an extension of the average lifespan of SMD, from the typical 2–3 years to 3.5 years. This indicates the feasibility of adopting user-empowerment-oriented models within the S.PSS–SMD context.

Overall, the analysis of SMD-related offerings through Tukker’s PSS typology reveals strong parallels between emerging SMD business/offer models and concepts of sustainable PSS. While many current practices in the SMD sector align with product-, use-, or result-oriented S.PSS, their potential to generate sustainability benefits often depends on how ownership, service integration, and user roles are configured. From trade-in schemes and modular reparability to device leasing and pay-per-service models, these systems demonstrate promising routes for reducing environmental impacts and promoting win-win benefits. However, the success of such models depends on consumer acceptance and behavior, which remains a critical barrier in this context. Although economic incentives and technological innovation are important drivers, achieving meaningful sustainability outcomes through S.PSS in the SMD sector requires not only business innovation but also cultural and behavioral shifts. Therefore, deeper user engagement should be considered an integral element of S.PSS design. This highlights the importance of developing effective strategies for designing and implementing S.PSS models capable of addressing the sector’s unique barriers. Therefore, this study aims to explore how S.PSS can be tailored to support sustainability in the SMD sector, orienting the possible S.PSS–SMD model’s development/design.

3. Method Overview

To address the study’s aim, a qualitative research approach was undertaken to construct a conceptual framework that integrates main characteristics and archetypes for designing S.PSS for SMD. The methodological approach consisted of literature review, multiple-case analysis, development of an archetypal map, and expert validation. The schematic below (Figure 1) illustrates an overview of the process workflow.

The research began with a literature review to establish the theoretical underpinning and identify gaps in existing knowledge related to the S.PSS–SMD context. Literature from peer-reviewed journals and conference proceedings from Scopus, Web of Science, and Google Scholar covering 2010–2025 was reviewed using queries such as “Product-Service System,” “Servitization,” “Smart Mobile Device,” and related sustainability keywords (e.g., “environment *”). Despite the scarcity of relevant literature, this review distilled the principal S.PSS typologies and SMD-relevant constructs, thereby identifying preliminary characteristics and exposing clear empirical blind spots.

To further facilitate the identification of S.PSS–SMD characteristics (step 1), a qualitative multiple-case analysis was also adopted because this approach is suitable to emerging research domains and to the understanding of multifaceted socio-technical phenomena [56]. Following Strauss and Corbin’s guidance on inductive theorizing [57], cases were selected and coded iteratively to surface emergent patterns. To ensure that the sample reflected the widest possible variation in S.PSS configurations, the maximum variation sampling strategy [58] was adopted for the selection of cases. This means that the aim was to

sample for heterogeneity and select cases that maximize diversity in characterizing dimensions (e.g., different types of ownership arrangement, target customer, service focus). Since the objective was analytical generalization—to refine constructs and configurational relationships—rather than statistical inference, such heterogeneity increases the range of conditions under which emergent patterns are observed, thereby strengthening theoretical transferability [58,59]. It also heightens the external validity of the resulting conceptual framework while remaining consistent with qualitative principles that favor depth and contextual richness over statistical representativeness [60]. Accordingly, the dataset should be interpreted as an analytic corpus for pattern identification and framework building concerning configurational logics rather than population frequencies.

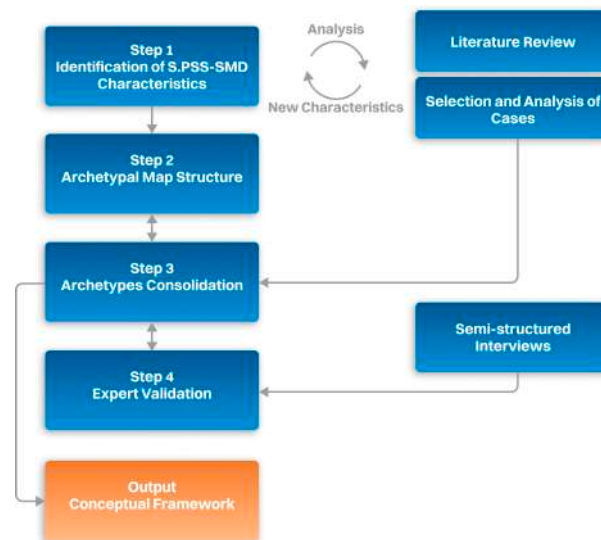


Figure 1. Method Overview.

The criteria for case selection required that each offer: (i) be commercially implemented or an active pilot for more than three months; (ii) combine physical SMD with at least one ongoing service (e.g., repair, refurbishment, upgrades, device management); (iii) state or evidence sustainability benefits (e.g., extended device lifespans, resource recycle or recovery); and (iv) have sufficient and publicly accessible information to support consistent coding and triangulation. Cases that lacked the criteria and checkable information (such as conceptual examples) were excluded to preserve construct clarity and comparability. Seventeen cases eventually satisfied these criteria. The set intentionally spans the three existing S.PSS orientations (product-, use-, and result-oriented) and comprises 9 B2C, 5 B2B, and 3 mixed (B2C and B2B) offers. Because the S.PSS–SMD space is emergent and documentation practices are uneven, the resulting sample shows a slight tilt toward well-documented European/Global-North markets and English-accessible sources. This reflects a methodological constraint (evidence availability) rather than a substantive claim about regional dominance. To mitigate selection bias, the cases were (i) required to have publicly verifiable documentation for consistent coding and cross-source triangulation; (ii) ensured coverage of all three S.PSS orientations and both B2C/B2B segments; (iii) applied a stopping rule based on cross-case saturation (no new characteristic combinations); and (iv) enhanced transparency by recording each offer’s brief (including market presence by region) in Table 1 and detailed case descriptions, cross-case analysis, and a descriptive tally in Appendix A.

Table 1. List of cases.

Cod	Case	S.PSS Type	Customer Type	Value-Proposition	Market (s)
#01	Fairphone	Product-oriented	B2C	Ownership	Regional; Europe (e.g., NL, DE), USA
#02	Teracube	Product-oriented	B2C	Ownership	Regional; Europe, UK, USA/CA
#03	SHIFTphone	Product-oriented	B2C	Ownership	Regional; Europe, NZ
#04	Crosscall	Product-oriented	B2C	Ownership	Regional; Europe, South Africa
#05	Samsung Enterprise Edition (Samsung EE)	Product-oriented	B2B	Ownership	Multi regional; Europe, Asia (e.g., SG, IN, PH, MY)
#06	Teracube Wireless plan	Product-oriented	B2C	Ownership	Single country; USA
#07	Fairphone Easy	Use-oriented	B2C	Access	Single country; NL
#08	Samsung Access	Use-oriented	B2C	Access	Single country; USA
#09	Raylo	Use-oriented	B2C and B2B	Access	Single country; UK
#10	Circular	Use-oriented	B2C and B2B	Access	Regional; SG and AU
#11	Grover	Use-oriented	B2C and B2B	Access	Regional; Europe, USA
#12	Cellhire	Result-oriented	B2C	Access	Global; multiple continents
#13	LG U + Rental	Result-oriented	B2C	Access	Single country; KR
#14	Hartford Technology Rental	Result-oriented	B2B	Access	Single country; USA
#15	Surface for Business Bundles	Result-oriented	B2B	Access	Regional; Europe (e.g., DE, FR), USA, AU
#16	Everphone	Result-oriented	B2B	Access	Regional; Europe
#17	Vodafone Business DLM	Result-oriented	B2B	Access	Regional; Europe, USA

“Europe” refers to the European continent (EU and non-EU countries, unless otherwise specified). Country abbreviations follow ISO-3166 [61] alpha-2 codes: USA = United States, CA = Canada, UK = United Kingdom, NL = Netherlands, DE = Germany, FR = France, SG = Singapore, AU = Australia, NZ = New Zealand, KR = South Korea, IN = India, PH = Philippines, MY = Malaysia, etc.

Data collection for each case was documented using an adapted version of the “S.PSS Concept Description Form” originally developed by the Learning Network on Sustainability (The Learning Network on Sustainability (LeNS) is an international network of more than 160 Higher Education Institutions and other Organisations aimed at the research, development, and diffusion of the design for sustainability discipline in worldwide research agendas and curricula with a multipolar, learning-by-sharing, open access ethos) [23]. This standardized template ensured consistency across case analyses and included key descriptive dimensions (e.g., case title, brief description, producer/providers, S.PSS classification, customer type, products (and ownership), services (and features), and sustainable benefits). To enhance reliability and reduce single-source bias, case data were triangulated using multiple sources, including corporate reports, industry analyses, media articles, and case studies by other scholars.

These cases were then examined iteratively through coding, guided by emergent dimensions initially identified from the literature and continually refined through case insights. Coding followed an iterative process informed by literature-derived dimensions and refined through cross-case comparison, and conceptual saturation was judged to be reached when additional cases no longer yielded new characteristic combinations relevant to the framework. Five S.PSS-SMD key dimensions with opposing poles and varying degrees (see Section 4) were finalized, informing the construction of a polarity-based archetypal map (step 2), designed following established visual mapping techniques demonstrated by Emili et al. [62]. Archetypal maps, defined as visual matrices that position real-world cases along orthogonal design dimensions, are instrumental in synthesizing complex and heterogeneous data sets, revealing strategic design spaces, and effectively communicating key insights across interdisciplinary teams [63]. In this study, the archetypal map served multiple critical functions: it visually communicated complex configurations, acted as an

analytical tool to cluster and saturate archetypes, and functioned as an ideation tool that spotlights under-explored design spaces and potential innovative business propositions within the SMD sector [63]. By populating this map and positioning the selected cases into it, it is possible to saturate characteristics by consolidating archetypes of S.PSS-SMD models (step 3). With the identification of S.PSS-SMD characteristics, the development of the archetypal map, and the saturation of the archetype's models, the conceptual framework is presented together with main reflections for the design of S.PSS for SMD.

Following the initial development of the archetypal map and saturation of identified archetypes, step 4 involved experts' validation of the preliminary framework with both academia and industry relevance to ensure theoretical and practical robustness. Three expert assessments were recruited from the Learning Network on Sustainability, comprised of academic professors on S.PSS/design for sustainability and three industry professionals on SMD-related offers. Sessions (~60 min) combined quick ratings with open feedback to surface ambiguities or omissions. The interview component was designed for framework assessment, following the information-power principle for qualitative inquiry [64,65]—a small, purposefully composed panel was appropriate because the aim was narrow, the guide was focused, and informants possessed high domain expertise. Finally, six semi-structured expert interviews were conducted, engaging a balanced mix of practitioners and academic specialists.

Overall, the experts validated the comprehensiveness and applicability of the framework with key insights on further clarification and refinement recommendations, e.g., sharpening the boundary between use- and result-oriented offers, and commonly highlighting the growing consumer awareness of sustainability and the significant potential of user behavior within the framework. These recommendations were subsequently integrated, significantly enhancing the clarity and practical utility of the conceptual framework.

4. Identification of S.PSS-SMD Characteristics

As presented in the method section, building on the existing knowledge base of S.PSS design and initial perception of the parallels between S.PSS and SMD, five groups of characteristics were adapted or identified to be applied as dimensions in the preliminary framework—S.PSS-SMD Type, Value Proposition and Sustainability Potential, Customer-differentiation, Service Delivery Approach, and Service Focus—each bringing a perspective to examine how S.PSS can be structured, delivered, and tailored within the SMD sector. These dimensions serve as a basis for identifying S.PSS archetypes by mapping the service components embedded in the SMD business ecosystem. This archetype's characterization, in return, also provided an iteration and improvements of the framework. The following sections present an overview of these dimensions and their potential contributions to sustainability.

4.1. S.PSS Types Applied to SMD and Value-Proposition and Sustainability Potential

Drawing from typologies of PSS innovation [22,27] and sustainable system innovation [22,66] and based on a synthesis of industry-specific characteristics, three primary types of S.PSS have been adapted as most relevant to the SMD sector. These models prioritize environmental and economic sustainability through different configurations of service and ownership.

- **Product-oriented S.PSS for SMD** innovation adding value to the device life cycle is defined as: “company/organization (or an alliance of companies/organizations) sells SMD to customers/users while providing all-inclusive lifecycle services (possibly complemented by customer-empowering services) to guarantee the lifecycle performance of the SMD (sold to customers/users) over a specified period. These

services typically encompass hardware-based solutions (e.g., customization, maintenance, repair, upgrading, substitution, take-back, end-of-life treatment; see Cases #02, #04), software-based solutions (e.g., OS upgrades, device management software; see Cases #05, #06), and/or communication-based solutions (e.g., data connectivity; see Case #06)."

- **Use-oriented S.PSS for SMD** innovation offering access to SMD for customers is defined as: "a company/organization (or an alliance of companies/organizations) provides access to SMD hardware usage with comprehensive lifecycle services, enabling customers to achieve specific satisfaction—namely, the use of the SMD—without ownership (customers pay solely for hardware access, typically charged per device or per period of device use). Services predominantly focus on hardware-based solutions (e.g., repair, upgrading, substitution, refurbishment; see Cases #7, #8, #9, #10), complemented by essential software-based solutions that support device use (e.g., OS upgrades). The providers ensure functionality of the device, leaving other management responsibilities to the customer (e.g., software and network connectivity)."
- **Result-oriented S.PSS for SMD** innovation providing "integrated bundles" for customers is defined as: "a company/organization (or an alliance of companies/organizations) offers a customized mix of services designed to achieve a final result (i.e., an integrated communication solution; see Cases #12, #13, #14, #17) for customers over an agreed period. Customers gain access to fully functional SMD and all-inclusive services, typically charged based on delivered outcomes or metrics (e.g., communication availability, data usage per month, or user-month of guaranteed connectivity). Services integrate hardware-based solutions (e.g., repair, upgrading, substitution), software-based solutions (e.g., software support, OS upgrades), and communication-based solutions (e.g., data connectivity; see Case #16). Providers commit to performance-level agreements (e.g., system uptime, data transfer speed, security configurations) and take responsibility for fulfilling these indicators."

From an ownership perspective, these three S.PSS-SMD types form two clusters: ownership-based models (product-oriented), in which customers acquire legal title to the device, and access-based models (use-oriented and result-oriented), in which providers retain ownership and grant customers the right to utilize the device or its functions [22]. Clarifying ownership is crucial in PSS design, directly influencing the customer value proposition—whether a tangible product, a bundled service, or a guaranteed performance result [67]—and determining responsibility allocation for lifecycle activities such as firmware patching, battery degradation, and second-life redeployment of high-value components (e.g., OLED screens or 5G radios). Furthermore, clearly defined ownership structures enable providers to formulate coherent revenue strategies, including product sales with complementary lifecycle services for ownership-based models, recurring subscription fees or pay-per-use models, and residual value recovery in access-based offerings [68,69].

The established continuum from product- through use- to result-oriented S.PSS-SMD highlights increasing service intensity and sustainability potential [70]. Product-oriented models typically provide targeted lifecycle services (e.g., device repairs, battery swaps), yielding moderate environmental benefits through extended device lifetimes. Use-oriented models enhance sustainability potential by facilitating higher device utilization rates, thus reducing per-service material and energy demands. Result-oriented models further amplify sustainability opportunities by remunerating providers based on performance outcomes rather than device usage alone. This incentivizes providers to optimize service efficiency, minimize resource consumption (e.g., less network-related energy use), and implement proactive maintenance and refurbishment strategies throughout the contract duration [71]. Such integrated approaches, particularly when leveraging software updates and network

connectivity, represent more strategic opportunities for sustainability gains within the SMD sector characterized by quick obsolescence and energy intensiveness.

4.2. Service Customer-Differentiation

Customer segmentation matters to S.PSS-SMD design and implementation because individuals and organizations display distinct preferences for ownership- versus access-based offers, cost structures, and sustainability incentives [22]. Drawing from the seventeen cases analyzed and the broader SMD literature, the study adopts two primary categories—business-to-consumer (B2C) and business-to-business (B2B)—and specifies typical sub-segments that designers should consider.

Individual customers (B2C) are end-users who acquire or subscribe to SMD primarily for personal use. Four recurrent sub-segments emerge:

- Price-sensitive users who react strongly to total cost and are willing to trade ownership and device performance for lower tariffs or refurbished devices. Mobile data pricing may double their price sensitivity [24].
- Eco-conscious users who deliberately seek low-impact or modular phones and are prepared to pay a green premium [72,73]; see also Cases #01 and #03.
- Status-driven or tech-prestige users attracted by cutting-edge specifications, luxury branding, or frequent device updates [74].
- Intermittent-need users (e.g., tourists, gig workers, or parents lending a handset) who prefer short-term rental or sharing schemes instead of ownership, and security-aware temporary-sharing solutions illustrate this niche [75]; see also Cases #12 and #13.

Business customers (B2B) procure devices to support organizational workflows and can be mapped along size and compliance needs:

- Small and medium-sized enterprises (SMEs) often choose straightforward leases that convert capital expenditures into predictable operating expenses and reduce financing constraints [76]; see also Cases #10 and #11.
- Large enterprises or public institutions increasingly usually demand full Device-as-a-Service (DaaS) contracts that bundle hardware, software, security, helpdesk, and end-of-life logistics under multiyear service-level agreements—an arrangement highlighted by both industry reports and studies [33,77]; see also Cases #15, #16, and #17.

Although other micro-groups may emerge in niche markets (e.g., household “family plans” or community collectives), current market evidence indicates that most scalable S.PSS propositions for SMD still fall under the B2C or B2B umbrellas described above.

4.3. Service Delivery Approach

Another critical characteristic identified in the analysis is the service delivery approach, which delineates how lifecycle services are allocated between provider and customer throughout the SMD’s lifespan. Three primary approaches are observed:

- **Provider Stewardship (provider-led approach):** Under provider stewardship, lifecycle management activities of devices (e.g., repair, refurbishment, or upgrades) are primarily planned, managed, and operated by the device producers, service providers, or their authorized partners. In this approach, providers strategically lead and coordinate these operational services, while customers mainly engage as end-users without extensive service responsibilities. Representative examples include Crosscall (Case #04), which guarantees maintenance and repair—including free battery replacements—for a five-year period, and subscription-based offerings such as Raylo (Case #09), Circular (Case #10), Grover (Case #11), and Samsung Access (Case #08), in which

providers actively manage lifecycle activities such as maintenance, upgrades, and device replacements. Similarly, result-oriented S.PSS models such as Cellhire (Case #12), LG Rental (Case #13), Hartford Technology Rental (Case #14), and Everphone (Case #16) extend provider stewardship to bundled services including network management and software support. According to Tukker [78], although industry circumstances vary, greater provider involvement in service delivery typically leads to higher innovation potential and stronger win-win sustainability outcomes. In use-oriented or result-oriented models, providers retain device ownership and thus naturally assume responsibility for device performance and service continuity throughout the contract period, reinforcing the strategic importance of provider stewardship.

- **Customer Empowerment (customer-empowering approach):** Customer empowerment refers to the approach in which customers are supported with necessary resources (e.g., tools, instructions, tutorials, or software) to independently perform selected lifecycle management tasks. A prominent example is provided by Fairphone (Case #01), which encourages and facilitates users in device self-repair or self-maintenance by offering publicly accessible technical documentation, comprehensive online repair tutorials, detailed manuals, and direct online support. Combined with package-included screwdrivers and module component availability for at least eight years, Fairphone enables users to address routine repairs independently and thereby extend device lifespan. Moreover, Fairphone actively fosters user community engagement through the Fairphone Community platform, where users exchange repair insights and software modifications and organize local repair events. Similarly, Shiftphone (Case #03) equips customers with repair manuals and a guaranteed long-term supply of spare parts to support self-managed repairs and hardware upgrades. Not only in the B2C cases presented above, but the customer-empowering approach also appears in B2B contexts. For instance, Samsung Enterprise Edition (Samsung EE, Case #05) provides enterprise IT teams with fleet tracking and management software, coupled with professional training. This software enables internal management of device fleets with different functionalities, including security management, predictive maintenance analytics, software updates (e.g., root settings, device ID tamper detection), device maintenance optimization, and mobile security protection, collectively empowering enterprises to extend device usability internally.
- **Hybrid Delivery:** Hybrid approach combines elements of both provider stewardship and customer empowerment within a single business offering, aiming to balance operational efficiency and customer involvement. Fairphone exemplifies this hybrid delivery, coupling extensive provider-managed services (e.g., extended device warranty and OS support) with customer empowerment through self-repair facilitation. Likewise, Samsung EE (Case #05) and Surface for Business Bundles (Case #15) balance comprehensive provider stewardship (i.e., offering extended warranty) with empowering enterprise customers through fleet management tools and analytical software.

In practical terms, the provider stewardship was commonly found in use- and result-oriented S.PSS, where providers often deliver comprehensive service packages due to their retained ownership of devices. However, no case that entirely relies on customer-driven services was found, recognizing that complete reliance on users for all lifecycle tasks would challenge user trust and system reliability. Therefore, the second approach was mostly included in hybrid approach cases as an emerging trend. Nevertheless, considering the dynamic tendency of two approaches in a hybrid situation, strategically introducing customer empowerment elements can lower provider operational costs (e.g., lower operational costs due to more customers' self-maintenance) and enhance overall sustainability (see Section 7.2).

4.4. Service Focus (E)

Building on earlier definitions, services associated with SMD can be categorized into three domains—hardware, software, and digital communication infrastructure—each playing a different role across the device’s lifecycle [1]. These domains can offer a structure for services configurations in S.PSS-SMD:

- **Hardware-based services** can be understood as tangible service interventions targeting the physicality of SMD—such as maintenance (Cases #05, #15), repair (Cases #02, #04), component upgrades or replacement (Cases #04, #09, #11), and end-of-life (EoL) processing (Cases #01, #10). As in most industrial applications of S.PSS, hardware-oriented services help extend device longevity. For instance, offering component replacement services—when technically and economically feasible—can reduce the frequency of full device replacements, thus lowering material throughput and waste generation. Even at the EoL stage, refurbishing critical parts or reusing materials extends their utility and environmental value. In the context of sustainability, particularly in its environmental dimension, hardware-based services are indispensable [8,20].
- **Software-based services** encompass digital offerings linked to the software ecosystem of SMD, including operating systems (OS) (Cases #01, #11), security protocols (Cases #05, #15), and value-added applications (Cases #02, #16). The significance of software lies in its role as the functional gateway through which users engage with the physical device. S.PSS models that incorporate software-based services have various potentials to enhance sustainability outcomes. For example, long-term OS support is vital to ensure continued usability of hardware over time (Case #01). The absence of timely software updates can compromise compatibility, functionality, and cybersecurity, leading otherwise functional devices to premature obsolescence [32,79]. Furthermore, security patches and digital tools can indirectly extend hardware lifespan by ensuring ongoing relevance and safety. In business-to-business (B2B) settings, embedded fleet management software plays a pivotal role in enabling real-time monitoring of device status (e.g., battery health and component wear). Such systems facilitate data-driven or predictive maintenance, thereby preempting major failures and extending the lifespan of entire device fleets. These platforms can also orchestrate centralized system updates and security controls across device groups, further reinforcing service longevity. Thus, software-centric services are particularly crucial in the SMD sector’s pursuit of sustainable value delivery [80,81].
- **Communication-based services** refer to backbone services that enable communication (Cases #14, #16) and data traffic (Cases #06, #13)—fundamental enablers for SMD functionality across diverse use scenarios. When telecommunications providers act as key stakeholders in S.PSS offerings, information communication (and related network and energy infrastructure) becomes a fundamental component of the service model. Traditionally, SMD manufacturers and network providers operate as distinct entities. However, under a life cycle-oriented system boundary, infrastructure—especially network connectivity—emerges as a critical enabler during the use phase and must be incorporated into holistic sustainability assessments. In practice, infrastructure providers increasingly offer integrated SMD-based PSS models. For example, the O2 “Boudge” model combines mobile connectivity and hardware under a bundled service contract. Users pay for network access while receiving the device through interest-free or low-interest installment plans. During the contract period, users benefit not only from connectivity but also from product lifecycle services (e.g., troubleshooting or replacement). At the end of the agreed term, ownership of the device is transferred to the user. In result-oriented models, providers may even lease both the device and the network together, eliminating the need for separate contracts and reducing

transactional friction. There also exist rental modes that combine device leasing with bundled network services, where users do not need to seek additional contracts with network providers, as everything is included in the bundle, which helps save time [23,42].

These three service dimensions—hardware, software, and communication (infrastructure)—are frequently integrated in practice and function interdependently due to the nature of SMD. The hardware serves as the physical foundation for digital functions, while the software animates the hardware and opens the interface for broader digital services via application installations and system configurations. None of these functions can operate meaningfully without supporting infrastructure, particularly network access, which underpins the core communication functionality of smart mobile devices. Thus, the triad is mutually reinforcing and collectively defines the operational viability of SMD-based S.PSS models.

5. Structuring the Archetypal Map

5.1. Position the Characteristics of S.PSS-SMD

As presented in the method, archetypal maps assist in identifying and saturating possible archetypes S.PSS for SMD. After the identification of S.PSS-SMD characteristics (step 1; presented in Section 4), the construction of the archetypal system was conducted. Figure 2 illustrates the structuring of the archetypal map (step 2), where the five cross-dimensional factors—identified from the literature review, coded, and clustered into two groups—are distributed as building blocks along two orthogonal axes (labelled A through E).

- A. S.PSS-SMD type: Product-, Use-, or Result-oriented configurations.
- B. Value-proposition and sustainability potential: Ownership- versus access-based propositions and their environmental leverage.
- C. Customer type: B2C sub-segments vs. B2B institutional segments.
- D. Service delivery approach: Spectrum from provider stewardship to customer empowerment.
- E. Service focus: Hardware-, software-, or communication-based service focuses.

Dimension A covers three key types of S.PSS-SMD, which conceptually overlaps with the value proposition and sustainable potential dimension (B). Specifically, the product-oriented S.PSS type aligns with ownership-based value propositions, while use- and result-oriented models align with access-based value propositions, holding stronger sustainable potential [70]. Additionally, different service focus dimensions (E) can also reflect changes in S.PSS-SMD types (e.g., result-oriented models often encompass all-inclusive service focuses; use-oriented models may only focus on hardware-based services). Therefore, dimensions A, B, and E are clustered into one group due to their nexus, collectively forming the y-axis.

Another group of dimensional factors (x-axis) is dominated by B2C and B2B customer types (C), representing different demand preferences in different implementation scenarios. For example, individual customers may be more concerned about price, new product updates, contract terms, and perceived risk, while business/institutional customers may focus on contract stability and management-related services. Dimension D represents service delivery approaches, which are represented by a gradient ranging from provider stewardship to customer empowerment. Since both approaches have the potential to be applied in B2C and B2B scenarios, they are incorporated into the X-axis as a pair of sub-factors.

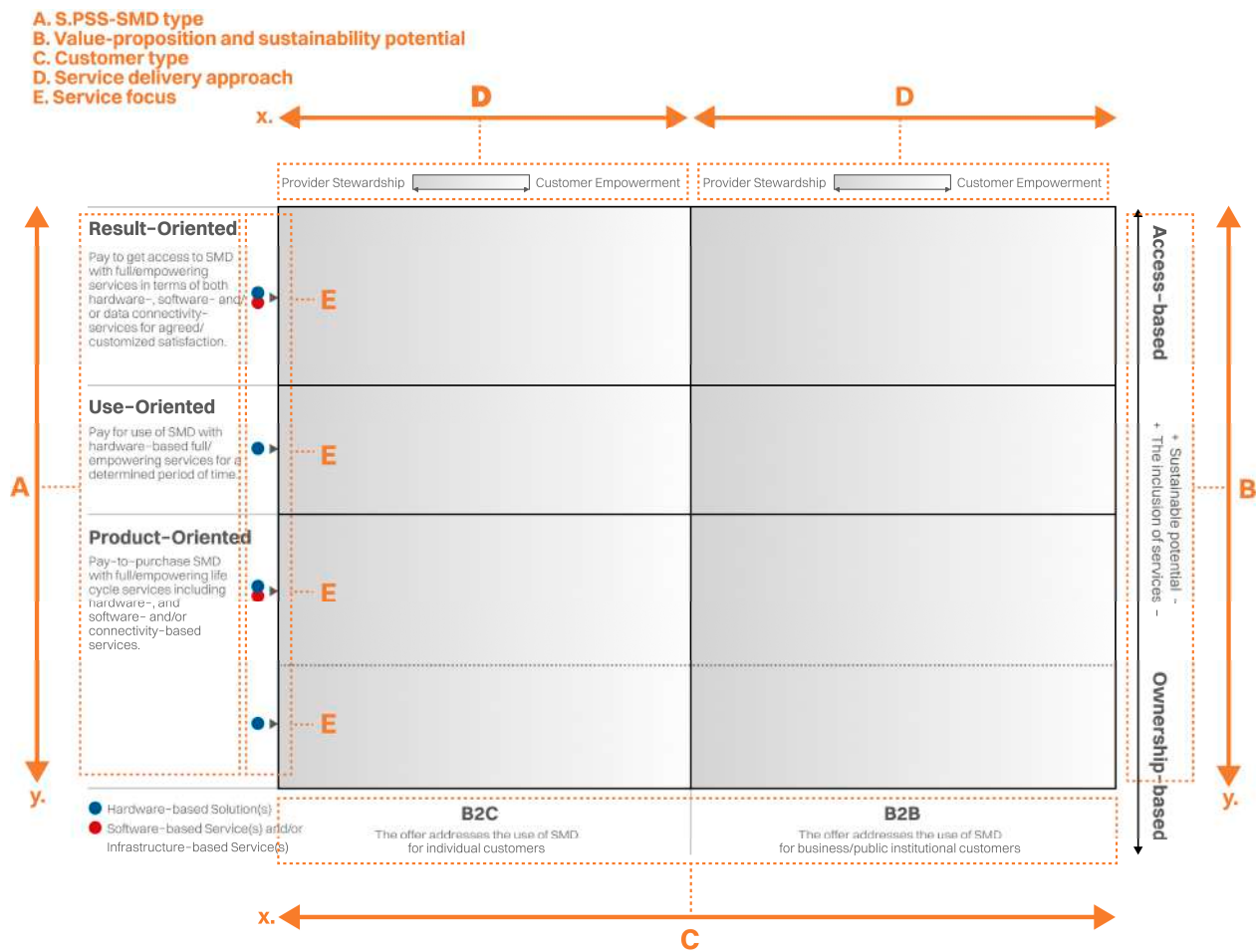


Figure 2. Combination of axis used (with dimension labels) for the map structuring (step 2).

5.2. Archetypal Map Structure and Base Development

After clustering the dimensions into the two orthogonal axes (vertical and horizontal), the diagram was prepared as a base for describing the S.PSS-SMD cases and being iterated into a new archetypal map (step 3). In fact, as stated in a previous section (The need for a new classification system), the goal is to build an archetypal system capable of simultaneously including key dimensions characterizing the models of S.PSS-SMD.

6. Archetypes Consolidation

6.1. Populating the Map and Clustering and Identification of Archetypal Models

With the above Archetypal Map in place, the seventeen analyzed cases were positioned as follows: the three horizontal bands denote S.PSS orientation (Product–Use–Result, reflecting increasing service inclusiveness and sustainability potential and ownership configuration), the lower horizontal axis shows customer segment (B2C and B2B), and the top ruler depicts the Service Delivery Approach (Provider Stewardship vs. Customer Empowerment). Each marker represents one case. Color encodes service focus (blue = hardware; red = presence of software and/or connectivity; dual-color = both), as shown in Figure 3.



Figure 3. Archetypal map populated with the selected cases (step 3).

After plotting, dense regions of similar configurations (ownership, delivery approach, service focus, customer type) were iteratively identified, and heuristic cluster envelopes were drawn (Figure 4). These clusters were subsequently stabilized into the archetypes after cross-checks and expert feedback, with text describing key configuration features of each model.

In total, twelve representative existing archetypal models were identified with the seventeen cases (Figure 5). Moreover, the discovery of gap areas in the framework indicates current shortcomings of practices and reveals opportunities for business model exploration.

Building on the map's dimensional logic, four missing archetypes were subsequently extrapolated to populate these vacant quadrants, completing the final archetypal map (Figure 6). Finally, expert interviews were conducted to evaluate and refine both the map structure and archetype models of S.PSS-SMD (step 4). Below, these archetypes were better described.

6.2. The Sixteen Archetypal Models

As a central component of the conceptual framework, the archetypal map and sixteen archetype models were developed to collectively guide designers and managers through a visualized classification of S.PSS models applicable to SMD. Although these archetypes can be potentially adaptable across various markets, the horizontal arrangement clusters models with similar service typologies into four primary groups.

The first group comprises Models 1, 3, 9, and 11, characterized by offerings strictly limited to hardware-related lifecycle services. Models 1 and 3, defined as "Selling devices with hardware-based lifecycle services", involve the outright sale of devices bundled with services centrally managed by producers or service providers. However, they distinctly differ in their target customers: Model 1 focuses on individual consumers, emphasizing services such as device repairs and system upgrades (Figure 7), whereas Model 3 targets businesses or public institutional customers, with a stronger emphasis on managing fleets

of devices through maintenance, repair, and fast replacement services. In contrast, Models 9 and 11, though maintaining similar market distinctions (individuals versus institutional customers), integrate more user-empowering elements into their hardware lifecycle services. Model 9 supports personal users with self-disassembly tools and knowledge-sharing resources, whereas Model 11 provides enterprises with tools and software for device management, employee technical training, and comprehensive maintenance programs.

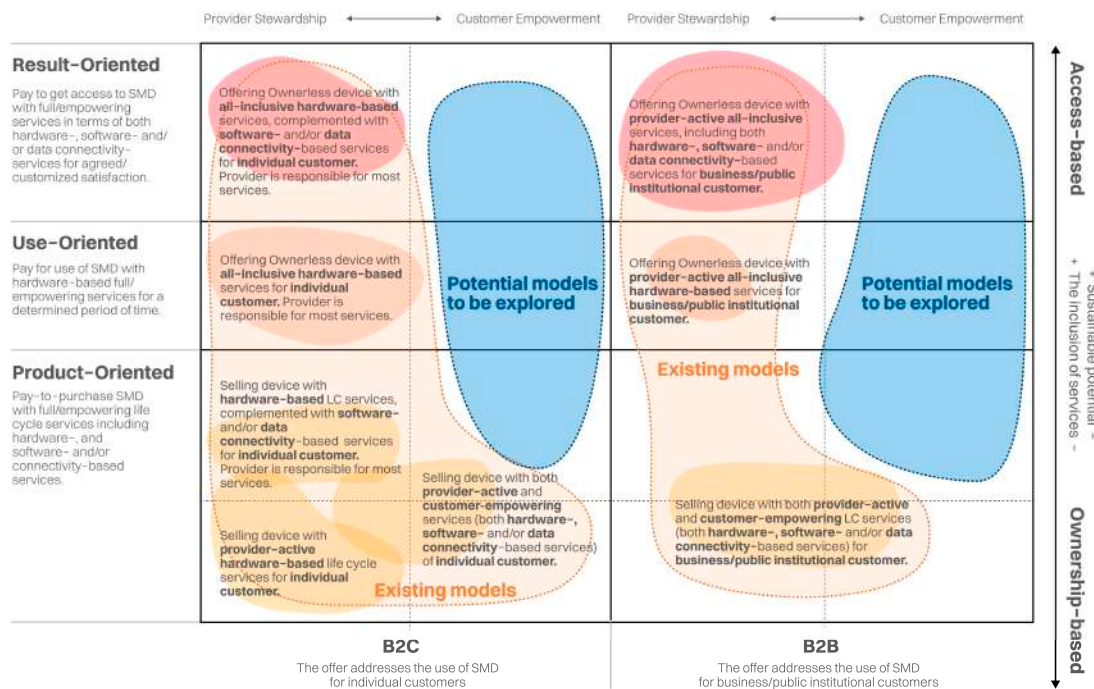


Figure 4. Archetypal map solidifying/saturating descriptions and models (step 3).

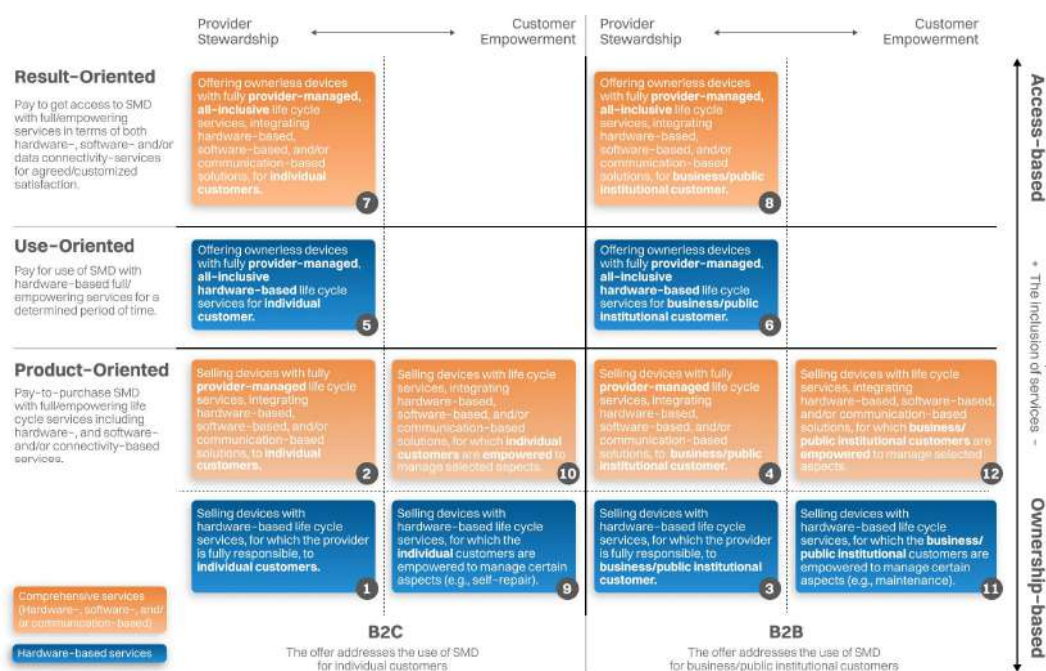


Figure 5. Consolidated Archetypes (step 3).



Figure 6. The conceptual framework with the archetypal map and 16 S.PSS-SMD business models.

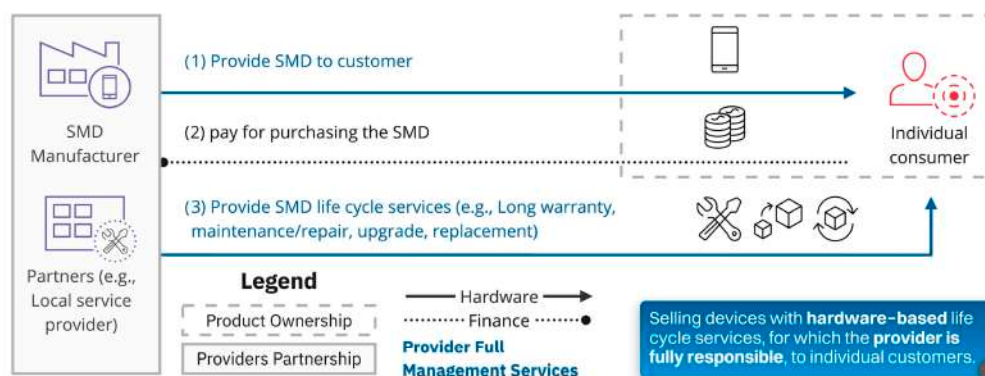


Figure 7. Example of archetype in the first group: model 1.

The second group, encompassing Models 2, 4, 10, and 12, extends beyond hardware-centric offerings by integrating additional services into software and connectivity. Specifically, Models 2 and 4—categorized as ‘Selling devices with hardware-based lifecycle services, complemented by software and connectivity services’—address individual and institutional customers, respectively. These models offer comprehensive packages including continuous OS updates, software compatibility assurances, cybersecurity measures, customized software management, and bundled network connectivity services. Models 10 and 12 parallel these distinctions but notably enhance their offerings through user empowerment features. For instance, users in Model 10 receive open-source or management software enabling them to independently track hardware performance and connectivity usage, whereas Model 12 equips enterprises with advanced device fleet monitoring tools, centralized software upgrades, software customization options, and open-source platforms facilitating autonomous management of device ecosystems (Figure 8).

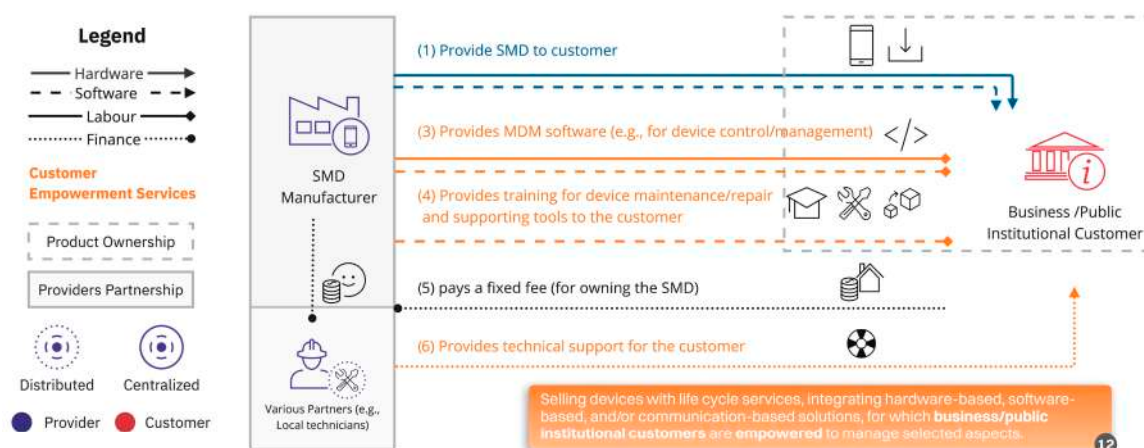


Figure 8. Example of archetype in the second group: model 12.

The third group, comprising Models 5, 6, 13, and 14, introduces access-based (use-oriented) archetypes. Models 5 and 6, defined as “Offering ownerless devices with all-inclusive hardware lifecycle services,” target individual (Model 5; Figure 9) and institutional (Model 6) customers by providing devices on a subscription or leasing basis. Customers benefit from seamlessly functioning devices without ownership obligations or maintenance responsibilities, typically within contractual durations ranging from a single day to multiple years. Models 13 and 14 may adopt a similar access-oriented approach with additional user empowerment dimensions. These models (Model 13 for individual users and Model 14 for institutional customers) integrate empowering support services such as user-driven maintenance tools, repair guidance, and accessible hardware management systems. Consequently, these models not only facilitate resource efficiency by extending product lifecycles but also promote active customer engagement, potentially leading to enhanced sustainability outcomes.

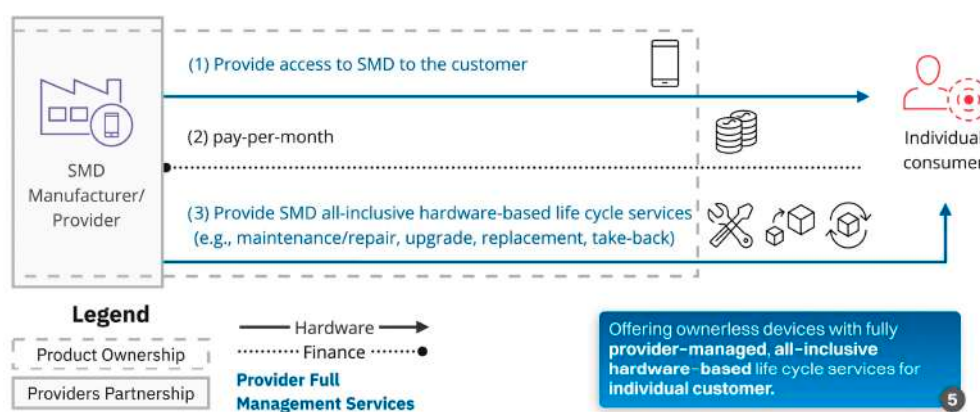


Figure 9. Example of an archetype in the third group: Model 5.

The fourth and final group, consisting of Models 7, 8, 15, and 16, represents result-oriented archetypal opportunities in the SMD domain. Models 7 and 8, described as “Offering ownerless devices with comprehensive hardware lifecycle services complemented by extensive software and communication-based services,” cater respectively to individual (Model 7) and institutional (Model 8) clients. These models bundle devices with robust software ecosystems and mobile/Wi-Fi network solutions, delivering holistic communication packages akin to communication-as-a-service or mobile-network-as-a-service models. Models 15 and 16 maintain similar customer distinctions yet stand apart by emphasizing

user empowerment patterns. Model 15, for instance, provides individual customers with bundled data services along with software tools enabling self-management of device and data usage, often incentivized economically (e.g., discounts for reduced data consumption). Conversely, Model 16 empowers institutional customers by offering device management software, advanced security control solutions, repair kits, and remote training programs (Figure 10). Although some real-world services exhibit similar features, archetypes 15 and 16 currently remain less prevalent as fully realized S.PSS offerings within the SMDS market.

Each archetype represents a different market scenario due to their distinct combinations of characteristics. Models within the “Product-oriented × Provider Stewardship” spectrum (1 and 2) suit retail and warranty-sensitive contexts where right-to-repair/spare-parts availability and extended OS support credibly extend lifetimes. Models 3 and 4 are attractive to enterprises standardizing on longer device refresh cycles. “Product-oriented × Customer Empowerment models (9 and 10) align with prosumers and communities that value modularity, repair culture, and open documentation, capturing value through self-service maintenance and upgrades. “Use-oriented × Provider Stewardship” models (5 and 6) serve individuals seeking always-current devices or specialized short-term use and SMEs/enterprises pursuing “Capital Expenditure to Operating Expenditure” conversion, predictable refresh, and compliance-ready fleet services, provided reverse-logistics and residual-value markets exist. “Use-oriented × Customer Empowerment” for enterprise (Models 11 and 12) fits organizations with in-house IT capabilities, cost-control requirements, or information-security needs—providers supply the lease and critical support while client IT handles day-to-day configuration and care. In the “Result-oriented × Provider Stewardship” spectrum, model 7 suits time-bound or project-based deployments (e.g., events, temporary sites, field campaigns) where a provider delivers communication-ready bundles on outcome terms; 8 is most viable in regulated/mission-critical domains when Service Level Agreements (uptime, security, throughput), modern connectivity (eSIM/5G), and data-protection governance are in place. Although models 15 and 16 are not yet widely implemented, they represent “Result-oriented × Customer Empowerment” whitespace configurations (e.g., micro-groups or co-ops combining outcome-based connectivity with shared self-service tasks) that become feasible as data-erasure standards, eco-design incentives, and private-network options mature.

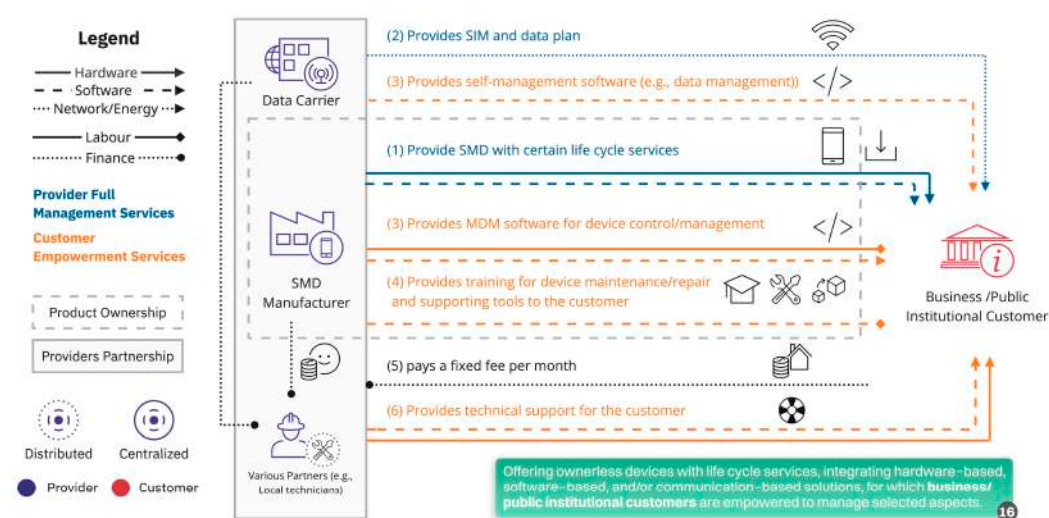


Figure 10. Example of archetype in the fourth group: model 16.

Overall, this archetypal map clarifies the existing landscape and uncovers potential white spaces to guide sustainable SMD innovation. The proposed framework offers

strategic value by systematically presenting comprehensive yet intuitive categorizations, enabling stakeholders to effectively identify and pursue design opportunities aligned with sustainable business objectives.

7. Opportunities and Challenges in Designing S.PSS Applied to SMD

This section synthesizes the critical insights from the archetypal map and classification analysis, discussing key opportunities that can leverage environmental benefits when designing S.PSS-SMD and how the framework can support such design processes, complemented with key challenges and recommendations for future design directions.

7.1. Addressing Device and Use-Phase Network Sustainability

Extending the longevity of smart mobile devices is a key sustainability strategy, particularly because the upstream processes and production phases are the most environmentally intensive [8,11]. S.PSS models support this goal by redefining stakeholder responsibilities and incentives. In use-oriented and result-oriented models (e.g., Models 5–8), where producers/providers retain ownership, they are motivated to design, produce, and deliver durable, easy-to-maintain/repair, and upgradable devices complemented by services to reduce recurring costs tied to production, distribution, and disposal. Profitability is thus driven by prolonged service periods rather than frequent replacements. Product-oriented models (e.g., Models 1–4, 9–12), while transferring ownership to users, still encourage providers to ensure long-term lifecycle support—through services like extended warranties and software updates—thereby incentivizing design strategies that promote repairability, maintenance, and upgradeability [82].

As consumer awareness of sustainability increases [42], companies offering such service-integrated, durable products can strengthen their market appeal. Furthermore, providers benefit economically by maximizing device utilization and recovering value from components and materials once devices are no longer viable, thus minimizing resource waste. In regulatory contexts like the EU, ownership retention also drives responsible material choices to reduce hazardous waste and disposal costs. While sustainability priorities vary across the sixteen archetypes proposed in this research framework, they all share a fundamental goal: decoupling profitability from device sales volumes and mitigating technological obsolescence to support systemic innovation and sustainable consumption transitions.

Complementary, on the energy consumption side, unlike traditional product industries such as textiles or furniture, where environmental impacts are concentrated in the material extraction and production phases, the SMD industry involves a more complex ecosystem comprising hardware, software, and data-communication infrastructure. Recent studies [9,38,83] revealed that Life Cycle Assessments (LCAs) have often underestimated the environmental impact of the use phase, particularly due to overlooked factors like network connectivity and data transmission. Secchi [84] highlighted that when data traffic is included in LCAs, the use phase emerges as the most environmentally intensive, surpassing the combined impact of upstream processes and production by over 500%. This finding underscores the importance of prioritizing energy efficiency during the operational phase, a distinctive sustainability concern in the SMD sector and S.PSS design.

Consequently, effective S.PSS-SMD models should incorporate not only device manufacturers but also telecom and infrastructure providers, including energy suppliers where relevant. Integrating these actors into the business model enables systemic opportunities for win-win sustainability gains. For example, telecom providers offering unlimited data plans may benefit economically from reducing data usage through software optimization (i.e., the less data users consume, the lower the cost for providers), which concurrently lowers

energy consumption. Given the limited but growing body of research on the environmental effects of digital infrastructure, S.PSS design in the SMD sector should treat data-related impacts as a core consideration. To that end, designers and business developers are encouraged to engage telecom stakeholders as strategic partners across both ownership-based and access-based configurations—particularly in Models 2, 4, 7, 8, 10, and 12. Bundled offerings that comprehensively integrate hardware, software, and connectivity services—such as Communication-as-a-Service or pay-per-data solutions—are recommended to unlock the full sustainability and economic potential of S.PSS-SMD approaches.

7.2. Customer Empowerment

The role of the customer-empowering approach in the design of S.PSS-SMD needs to be highlighted due to its win-win lever. Evidence from the cases (#01, #03, #05) suggests that customer empowerment contributes significantly to win-win outcomes by reducing providers' operational costs and enhancing resource efficiency through user-driven maintenance and care. For customers, especially when combined with clear economic incentives such as discounts or loyalty rewards, these empowerment strategies become attractive. Crucially, empowering customers directly contributes to extending the lifespan of devices, thus amplifying environmental benefits.

Beyond direct economic and environmental benefits, empowering customers can foster psychological and emotional connections between users and devices, enhancing responsible usage patterns. Chapman [85] argued that personal investment in maintenance activities fosters pride, accomplishment, and stronger attachment, motivating prolonged and careful device use. Other studies also highlighted the potentials that involving users in repair and maintenance activities may cultivate emotional attachment and a heightened sense of ownership [54,55].

Despite these potentials, currently, customer-empowering approaches have predominantly been implemented only within product-oriented S.PSS models, where customers inherently bear most of the life-cycle responsibilities. Figure 11 shows an adjusted visualization of the framework. It modified the archetypal map's axes to represent service management types instead of customer segments, revealing underexplored opportunities particularly concentrated in access-based models, including use-oriented and result-oriented categories. This adjusted perspective distinctly highlights a noticeable gap in existing academic and practical discussions surrounding customer empowerment in access-based SMD offer contexts.

However, in scenarios where robust monitoring and incentive mechanisms are established, even models in which customers lack ownership can potentially integrate customer empowerment features to achieve sustainability outcomes. Archetypes encompassing Models 9 through 16 exemplify significant opportunities. For instance, providers can offer tailored software tools enabling customers to actively manage data usage and device maintenance, incentivized through economic rewards such as reduced subscription fees for responsible usage patterns. Such empowerment-based models not only optimize resource efficiency and reduce lifecycle costs for providers but also strengthen consumer relationships and market differentiation. Strategically implemented, customer empowerment can thus transform passive consumers into proactive sustainability partners, enhancing overall sustainability impacts and business resilience within the SMD sector.

7.3. Potential Challenges for Design and Implementation

While the archetypal map illuminates win-win opportunities, the practical deployment of S.PSS-SMD is fraught with multifaceted challenges that demand careful mitigation in the design process. A first concern is the rebound effect—the risk that efficiency gains

achieved by extending device lifetimes or optimizing utilization rates are offset by increased overall consumption [68]. If subscription fees and pay-per-use pricing significantly lower the cost of accessing high-specification devices, latent demand may be unlocked, potentially neutralizing environmental savings. Designers must therefore embed demand-management mechanisms, such as tiered tariffs that reward lower data traffic or longevity bonuses that discourage premature device upgrades.

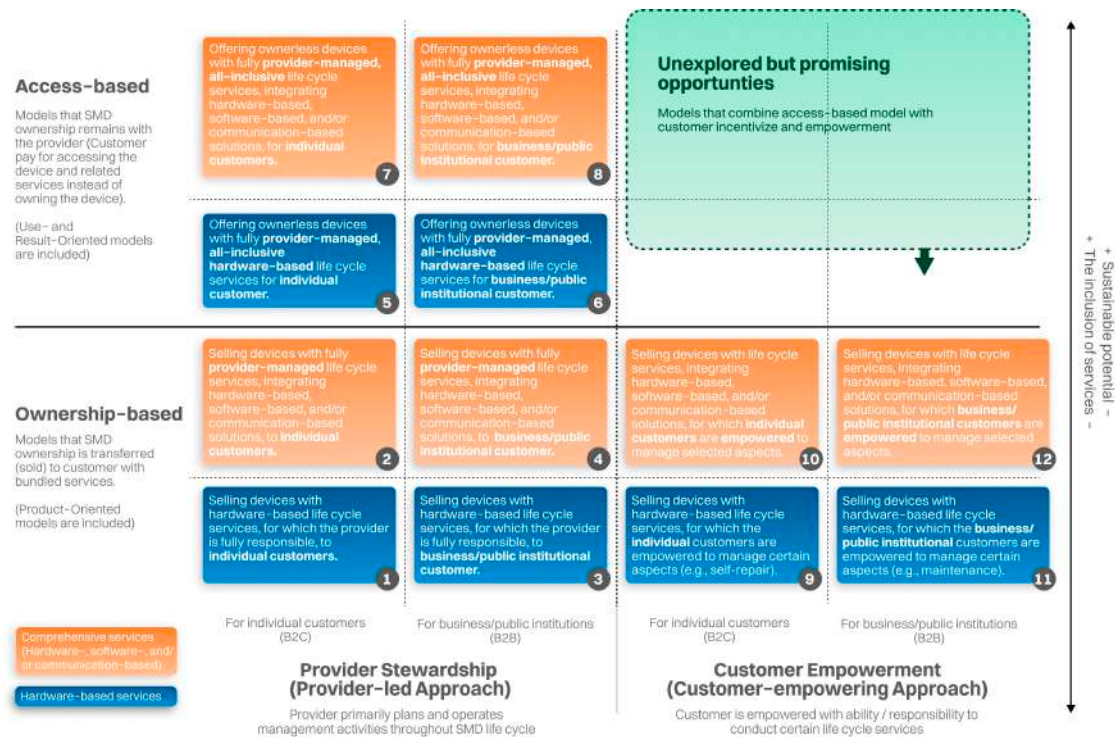


Figure 11. Adjusted visualization of the framework to highlight customer empowerment opportunities.

A second challenge lies in data-intensive service backbones. Many use- and result-oriented archetypes rely on continuous connectivity, cloud analytics, and over-the-air updates. While these services enable predictive maintenance and software longevity, they may shift impacts from the manufacturing to the operational phase by amplifying network energy demand. Life-cycle modelling should therefore account for these indirect burdens, and providers are suggested to privilege low-carbon data centers, edge-computing architectures, and data sobriety principles.

The third obstacle concerns privacy and cybersecurity. Retaining ownership of devices and collecting real-time performance data are essential for closed-loop asset management, yet they raise legal and ethical issues. Compliance with regulations such as the EU GDPR [86] and the forthcoming EU Artificial Intelligence Act [87] requires robust consent management, encryption-by-design, and transparent data-governance frameworks—features that add complexity and cost to S.PSS deployment.

Fourth, reverse-logistics capacity is still underdeveloped in many regions. High-quality refurbishment and component harvesting depend on efficient collection networks, diagnostic capabilities, and verified secondary-market outlets. Without these, providers may struggle to realize predicted residual values, undermining business viability. Public-private partnerships and investment in diagnostic automation can help bridge this infrastructure gap.

Additionally, the digital divide can inadvertently widen if access-based models bundle premium maintenance features with higher subscription tiers. Low-income user groups

risk being excluded from durability benefits, running counter to sustainability's social dimension. Inclusive tariff structures and device-leasing schemes targeting price-sensitive segments are thus imperative.

7.4. Strategic Design Implications

The proposed framework offers practical relevance to established companies operating in the SMD sector as well as start-ups or new entrants seeking to innovate within the space. It can assist designers and managers in exploring viable win-win opportunities through strategic design in the following pathways:

- **Understanding the key characteristics of S.PSS in the SMD sector:** The framework provides a specialized knowledge base tailored to S.PSS-SMD model applications, moving beyond general insights to identify specific system innovation features and model types. It introduces an archetypal classification system synthesizing existing cases and emerging models into a structured map, helping designers and managers understand the features of prevailing practices and untapped potential. Though developed with a focus on SMDs, this framework is broadly transferable to other industries increasingly defined by the convergence of hardware and software, such as smart home appliances.
- **Positioning and analyzing current business offerings:** The archetypal system supports managers and strategic designers in mapping their existing products, services, or S.PSS offerings to the framework, clarifying the firm's current position. A single company may position multiple offerings across the model map. For example, a company may provide two parallel S.PSS options: one option is a subscription-based offering, where the provider is active in all-inclusive service delivery, while the other option sells SMD with strong customer-empowering services, where the customer is more responsible for device life cycle management with economic incentives (e.g., discounted or credit rewards for self-repair). The framework also enables strategic mapping of the market landscape, allowing firms to assess geographical, policy, and sector-specific dynamics. Competitor offerings can also be visualized and summarized, informing business planning and innovation trajectories. A device manufacturer, for example, may identify new opportunities by partnering with telecom providers to seek for transformation from product- to result-oriented models.
- **Exploring and designing new business opportunities:** In alignment with the two functions above, the framework assists managers and designers in mapping the current state of specific contexts or regions to identify new business opportunities for expanding product portfolios through visualizing product repositioning and recombination. Once unmet offerings or model archetypes are identified, companies can reconfigure their portfolios to target those gaps. For instance, a firm currently providing leasing services to large B2B clients might expand into underserved B2C markets by adapting their offering to individual or small-group users.

By enabling such strategic explorations, the framework equips stakeholders to envision and implement sustainable innovation pathways for the future of the SMD industry.

8. Conclusions

This study aimed to address the knowledge gap of the absence of an SMD-specific S.PSS design framework and the limited ability of generic S.PSS classification systems to operationalize design choices in SMD ecosystems. For that, it develops a conceptual framework for the design of S.PSS tailored to the SMD sector. It applies a mixed-method approach, combining a literature review, multiple-case analysis (ex-post-facto) of seventeen market offerings, and expert assessment through semi-structured interviews. The study

derived a polarity-based archetypal map and identified sixteen archetypal business models. These archetypes span the three classical PSS typologies and capture the full spectrum of service focuses, customer types, ownership allocations and value propositions, sustainable potential, and customer empowerment levels currently (or potentially) observable in the SMD landscape, collectively forming a conceptual framework.

Compared with existing general S.PSS knowledge, the proposed framework contributes to extending S.PSS to the SMD sector, characterized by rapid obsolescence, high material intensity, and complex software-hardware-communication interdependencies. The framework introduces a Service Delivery Approach axis (Provider Stewardship vs. Customer Empowerment) that makes performance responsibility and lifecycle task allocation explicit and links them to sustainability potential, elevating connectivity to the same analytic level as hardware and software, reflecting communication-centered logics critical of the sector, and translating these dimensions into a polarity map that integrates heterogeneous evidence and surfaces white-space configurations not visible in generic schemes. In this sense, theoretically, the framework is a sector-grounded operationalization of existing PSS theory that remains compatible with the existing product/use/result triad. From SMD and a practical standpoint, it offers designers, managers, and policy-makers a visual decision aid to (i) benchmark existing portfolios, (ii) reveal potential formations as unoccupied white spaces, and (iii) stimulate the creation of novel, win-win PSS propositions that decouple economic value from linear throughput. The discussion highlights three promising leverage points in the design of S.PSS-SMD: (1) the enabling effect of S.PSS adoption on enhancing the sustainability potential of SMD hardware (e.g., by facilitating device lifespan extension); (2) the critical value of integrating network/communication-based solutions into S.PSS-SMD—especially in result-oriented models; and (3) the potential of customer empowerment in S.PSS-SMD design, particularly within product-oriented configurations. Additionally, the study also discusses systemic challenges such as rebound effects, data-intensive service backbones, privacy concerns, reverse-logistics bottlenecks, and regulatory fragmentation.

For design and industry practice, the archetypal map can be deployed in strategic workshops to align multidisciplinary teams around explicit sustainability targets, stakeholder configurations, and lifecycle responsibility allocations. By overlaying quantitative life-cycle data or market-specific constraints, the map can evolve into a dynamic road-mapping tool that guides iterative prototyping and go-to-market decisions. Policy-makers may likewise employ the classification to identify which archetypes warrant supportive regulation—such as extended producer responsibility credits or right-to-repair mandates—and where stricter guardrails are needed to prevent unintended rebound.

Some factors that limit the generalization of the finding should be acknowledged. First, the seventeen cases were selected to maximize variation rather than statistical representativeness. Evidence availability and language accessibility shaped the sampling: the case set privileges offerings with rich, publicly verifiable documentation, which results in a global north tilt to a lesser extent. This should not be read as the absence of alternative archetypes in other regions (e.g., African or Latin American markets), where disclosure practices and channel structures differ. Second, the environmental sustainability reasoning presented is qualitative and diagnostic by design; it does not yet include a comprehensive, quantified assessment of embodied impacts and in-use energy across device–software–network layers, nor does it model rebound dynamics. Moreover, although relevant concepts are mentioned, the socio-ethical dimension of sustainability falls outside the scope of this article. Fourth, end-user triangulation was not undertaken because the current contribution targets provider-level design: expert interviews were used for content assessment rather than theory saturation.

Future research should first focus on translating the proposed framework into co-creation tools and deploying it in co-creation workshops and pilot implementations with providers and enterprise customers to test usability, governance fit, and adoption under real operating conditions. Insights from these pilots can then be looped back to refine the framework and prioritize investable archetypes. Second, to couple the archetypal map with ISO-conformant LCA and complementary techno-economic analysis to quantify net sustainability effects (including potential rebound) across hardware, software, and connectivity layers, and to compare archetypes under diverse policy and market scenarios. Finally, to extend empirical coverage to under-represented regions and customer segments (e.g., informal/prepaid ecosystems and micro-groups such as households or community collectives) to probe archetype stability, reveal context-specific variants, and integrate social equity considerations into S.PSS-SMD design.

In conclusion, the proposed framework transcends a mere classificatory exercise to function as a strategic compass for designers, managers, and policymakers navigating the complex transition toward sustainable digital systems. By foregrounding the interplay between service logic, stakeholder incentives, and lifecycle responsibility, it charts actionable pathways for transforming smart mobile devices from short-lived commodities into long-lived, high-value service assets—a shift that is indispensable for meeting the environmental and economic imperatives of the digital era.

Author Contributions: Conceptualization, H.S., A.C.C.P. and C.V.; Methodology, H.S., A.C.C.P. and C.V.; Formal analysis, H.S., A.C.C.P. and C.V.; Investigation, H.S., A.C.C.P. and C.V.; Writing—original draft, H.S., A.C.C.P. and C.V.; Writing—review and editing, H.S., A.C.C.P. and C.V.; Supervision, C.V.; Project administration, H.S. and C.V. The work is the result of a collaborative effort among the authors. Sections 1–3 were authored by C.V., Sections 4 and 5 were authored by H.S., and Sections 6 and 7 were authored by A.C.C.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the China Scholarship Council under Grant 202208060131 and Politecnico di Milano Scholarship of doctorate of the PNRR code 38-411-16-DOT1316795-1540.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Politecnico di Milano (22 October 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Description and key characteristics of cases. Descriptive tally. Customer type (n = 17): B2C (n = 9), B2B (n = 5), mixed B2C/B2B (n = 3). Market presence by region: Europe (n = 11), North America (n = 9), other regions incl. Asia-Pacific and Africa (n = 8). Because multiple cases operate across multiple regions, the counts exceed the total of 17 cases.

Cod	Offering/Company	Short Description	S.PSS Type (Value Proposition)	Customer Type	Market(s)	Service Delivery Approach	Service Focus	Key Environmental Benefits
#01	Fairphone	Fairphone sells modular smartphones with 5-year hardware warranty and long-term software updates, complemented with enabling services (e.g., spare part accessibility, repair guides, peer-support forum) that encourage and support users to maintain/repair/upgrade their phone by themselves to ensure extended device lifespan.	Product-oriented (Ownership-based)	B2C	Regional; Europe (e.g., NL, DE), USA	Hybrid	HW + SW	Device lifespan extension; Material life extension (recycling); Resources' (Material) Renewability/Biocompatibility
#02	Teracube	Teracube sells unlocked smartphone bundled with a 4-year warranty that covers all parts, labour and two-way shipping, includes an express replacement device if repair exceeds 3 days, and offers flat-fee accidental damage repair (USD 39) along with 3 years of OS & security updates.	Product-oriented (Ownership-based)	B2C	Regional; Europe, UK, USA/CA	Provider stewardship	HW + SW	Device lifespan extension; Material life extension (recycling); Resources' Toxicity/Harmfulness Minimization
#03	SHIFTphone	SHIFTphone sells modular smartphones (with deposit) that combined with a 5-year upgrade & repair promise, complemented with self-disassembly tools, manuals, and a spare-part availability, enabling customers to repair/upgrade their own devices while reclaiming the deposit when returning phones for remanufacture.	Product-oriented (Ownership-based)	B2C	Regional; Europe, NZ	Hybrid	HW	Device lifespan extension; Material life extension (recycling); Resources' Toxicity/Harmfulness Minimization
#04	Crosscall	Crosscall sells rugged smartphones bundled with a 5-year manufacturer warranty and damaged/degraded battery replacement, and a 10-year spare-part availability pledge. Its European repair centers and trade-in service further close material loops for especially industrial and outdoor users.	Product-oriented (Ownership-based)	B2C	Regional; Europe, South Africa	Provider stewardship	HW	Device lifespan extension; Material life extension (recycling); Resources' Toxicity/Harmfulness Minimization
#05	Samsung Enterprise Edition (EE)	Samsung's EE bundle includes selected Galaxy devices sold with 3-year enhanced warranty, 5 years of security/OS updates, one-year Knox Suite license. While customers receive all-inclusive service guarantees, their IT admin can use the customized software to manage their device lifecycle internally.	Product-oriented (Ownership-based)	B2B	Multi regional; Europe, Asia (e.g., SG, IN, PH, MY)	Hybrid (customizable)	HW + SW	Device lifespan extension; Device use intensification; Resource consumption minimization

Table A1. Cont.

Cod	Offering/Company	Short Description	S.PSS Type (Value Proposition)	Customer Type	Market(s)	Service Delivery Approach	Service Focus	Key Environmental Benefits
#06	Teracube Wireless plan	Teracube bundles its phone with an unlocked SIM plan (network), complemented with 4-year warranty, flat-swap service, management software, etc. Customers own the device, while package of connectivity, extra warranty and sustainable perks (planting a tree for each customer) are delivered as an integrated subscription.	Product-oriented (Ownership-based)	B2C	Single country; USA	Provider stewardship	HW + SW + C	Device lifespan extension; Resource consumption minimization
#07	Fairphone Easy	Fairphone Easy is a pilot project that offers subscription-based smartphone bundled with all-inclusive life cycle services (e.g., delivery, repair, upgrade, swap, refurbishment). Customers pay monthly fee for accessing the devices usage without owning the devices.	Use-oriented (Access-based)	B2C	Single country; NL	Provider stewardship	HW + SW	Device lifespan extension; Device use intensification; Resource consumption minimization; Material life extension (recycling)
#08	Samsung Access	Samsung Access offers ownerless smartphones to customers through a flexible monthly device subscription that bundles warranty, accidental-damage cover, and optional nine-month upgrades, complemented with doorstep exchange and authorized repair services that keep devices functional and channel returned units into refurbishment loops.	Use-oriented (Access-based)	B2C	Single country; USA	Provider stewardship	HW	Device lifespan extension; Device use intensification; Resource consumption minimization; Material life extension (recycling)
#09	Raylo	Raylo leases SMD to customers on 12–36-month terms with all-inclusive services, including loss-and-damage protection and upgrade switches, complemented with prepaid returns, in-house refurbishment and second-life resale programs that circulate SMD across multiple users to extend device lifetimes and curb e-waste.	Use-oriented (Access-based)	B2C and B2B	Single country; UK	Provider stewardship	HW	Device lifespan extension; Device use intensification; Material life extension (recycling)
#10	Circular	Circular offers Device-as-a-service to individual users and companies, packaging the smart devices with pick-up/return logistics, protective accessories, repair/maintenance, refurbishment, component harvesting that sustain high utilization before final recycling.	Use-oriented (Access-based)	B2C and B2B	Regional; SG and AU	Provider stewardship	HW	Device lifespan extension; Device use intensification; Material life extension (recycling)
#11	Grover	Grover rents electronics (e.g., smartphones) via flexible 1–18-month subscriptions that include all-inclusive services (e.g., repair, damage protection, cascaded refurbishment, secure data wiping and redeployment processes, etc.) that keep devices in active circulation and reduce demand for new production.	Use-oriented (Access-based)	B2C and B2B	Regional; Europe, USA	Provider stewardship	HW	Device lifespan extension; Device use intensification; Material life extension (recycling)

Table A1. Cont.

Cod	Offering/Company	Short Description	S.PSS Type (Value Proposition)	Customer Type	Market(s)	Service Delivery Approach	Service Focus	Key Environmental Benefits
#12	Cellhire	Cellhire provides pooling unlocked smartphones paired with regional voice/data bundles for short/middle-term travel, complemented with 24/7 support, cleaning/maintenance, repair and redeployment services that maintain a high-utilization fleet and eliminate single-trip device purchases.	Result-oriented (Access-based)	B2C	Global; multiple continents	Provider stewardship	HW + SW + C	Device lifespan extension; Device use intensification; Resource consumption minimization; Material life extension (recycling)
#13	LG U+ Rental	LG U+ lets customers (normally travelers) rent a smartphone or pocket-Wi-Fi. Rental includes unlimited 4G/LTE data, local voice/SMS, optional eSIM/SIM upgrades. Users pay a daily or upfront bundle fee for accessing the "communication function", return the handset at any branch, and can extend or top-up online.	Result-oriented (Access-based)	B2C	Single country; KR	Provider stewardship	HW + SW + C	Device lifespan extension; Device use intensification; Resource consumption minimization; Material life extension (recycling)
#14	Hartford Technology Rental (HTR)	HTR provides short/long-term rentals of devices of different brands to enterprises, events and other agencies. Bundles include device kitting, staging with requested apps, SIM activation or mobile network/Wi-Fi modems, 24/7 swap-out & logistics, insurance, and certified data-wipe on return. Ownership stays with HTR and clients pay a weekly/monthly fee per device.	Result-oriented (Access-based)	B2B	Single country; USA	Provider stewardship	HW + SW + C	Device lifespan extension; Device use intensification; Resource consumption minimization; Material life extension (recycling)
#15	Surface for Business Bundles	Via authorized resellers (e.g., ALSO) Microsoft offers SMEs a subscription bundle for tablet, Microsoft 365 and optional teams management services. Fees cover the device, security & productivity apps, warranty, accidental-damage protection, next-day replacement and the right to refresh/return after 24–36 months.	Result-oriented (Access-based)	B2B	Regional; Europe (e.g., DE, FR), USA, AU	Hybrid	HW + SW + C	Device lifespan extension; Device use intensification; Resource consumption minimization; Material life extension (recycling)
#16	Everphone	Everphone procures, stages and ships phones to business employees. The employer pays a per-device monthly lease that includes MDM enrolment and software use training, secure dual-persona set-up, damage replacement within 24 h, and up-/re-cycling via its circular refurbishment partner. Optional data plans offered by its partners are also offered. Employees may privately upgrade or retain devices via salary add-on-aligning incentives for longer lifetime.	Result-oriented (Access-based)	B2B	Regional; Europe	Hybrid	HW + SW + C	Device lifespan extension; Device use intensification; Resource consumption minimization; Material life extension (recycling); Resources' Toxicity/Harmfulness Minimization

Table A1. Cont.

Cod	Offering/Company	Short Description	S.PSS Type (Value Proposition)	Customer Type	Market(s)	Service Delivery Approach	Service Focus	Key Environmental Benefits
#17	Vodafone Business DLM	Vodafone DLM supplies corporate fleets of smartphones/tablets under a single per-month, per-device price that covers procurement, zero-touch enrolment, 5G/4G airtime, break/fix swap, security/MDM, in-life analytics, certified recycling and residual-value credit. A self-service portal lets IT teams track orders, repairs and carbon-savings dashboards.	Result-oriented (Access-based)	B2B	Regional; Europe, USA	Provider stewardship	HW + SW + C	Device lifespan extension; Device use intensification; Resource consumption minimization; Material life extension (recycling); Resources' Toxicity/Harmfulness Minimization

HW: Hardware-based; SW: Software-based; C: Communication-based. “Europe” refers to the European continent (EU and non-EU countries, unless otherwise specified). Country abbreviations follow ISO-3166 alpha-2 codes: USA = United States, CA = Canada, UK = United Kingdom, NL = Netherlands, DE = Germany, FR = France, SG = Singapore, AU = Australia, NZ = New Zealand, KR = South Korea, IN = India, PH = Philippines, MY = Malaysia, etc.

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