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# Proceedings of IASDR 2023: Life-changing Design

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# IASDR Congress

# Life-changing design

Milan 9th—13th October

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EDITORS:
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Francesca Rizzo
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# Life-Changing Design

## Proceedings of the 10th Congress of the International Association of Societies of Design Research (IASDR 2023)

**EDITORS:**

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# Digital transition, sustainable product-service system (S.PSS), and environmental sustainability - a systematic review

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Recently, the ongoing digital transition has brought forth both new risks and opportunities for environmental sustainability. However, despite some attention given to potential relationships between related areas and a growing research interest therein, a limited number of studies have holistically explored the nexus between digital transition, PSS, and environmental benefits. This research is a systematic literature review focused on the relationship between S.PSS and environmental sustainability during the digital transition process. We propose a novel analytical perspective by synthesizing and mapping the existing literature to derive a potential pathway for digital technologies to optimize four S.PSS relevant factors through four primary approaches (Information/Data Access Optimization, Connectivity & Communication Optimization, Process Optimization, Systemic Optimization), leading to environmental benefits across six dimensions (Product lifetime extension, Intensive use of Product, efficiency of resources, resources' renewability, Material life extension and Pollution reduction), and outlining current shortcomings and suggested future research directions. This study identifies broad consensus on the potential significance of digital transition in contributing to the environmental benefits of the product design for environmental sustainability (i.e. Life Cycle Design), but reveals a scarcity of research focusing on other aspects of S.PSS (e.g. service and business model innovation) and environmental benefits (e.g. resource renewability), which need further investigation. This study assists researchers in comprehending the potential environmental impacts of digital technologies when applied to S.PSS, identifying future research priorities to inspire designers to revaluate the new role and competence of S.PSS in promoting sustainable transition in the digital era.

***Keywords: digital transition; sustainable product-service system; distributed economy; environmental sustainability***

# 1 Introduction

Digital transition (DT), also referred to as digital transformation (Vial, 2019), has led to profound and irresistible changes ranging from individual lives to socio-technical systems, spanning industries, organizations, and society as a whole. The transition encompasses the adoption and integration of digital technologies, such as the Internet of Things (IoT), big data analytics, and artificial intelligence (AI), to augment business operations, enhance customer experiences, and develop novel products and services (Majchrzak et al., 2016). However, this process has also engendered new conflicts and risks for our natural environment, as evidenced by the substantial resource and energy consumption, electronic waste generation, and other adverse consequences (Lange et al., 2020; Shittu et al., 2021).

In this study, we present a comprehensive analysis of the contemporary research landscape and practical applications concerning the metamorphosis of S.PSS, underpinned by digital technologies and ensuing digital transition. It is also identified that the accompanying potential for driving the digital transition of S.PSS and simultaneously creating sustainable value propositions is revealed by these investigations and practices. The study aims to address the following three research questions: 1) Which digital technologies are mainly employed in the digital transition of S.PSS? 2) How do these digital technologies optimize (or empower) S.PSS, and what environmental benefits do they offer? 3) What opportunities and challenges emerge for digital transition in future investigations of S.PSS?

The primary contribution of this study lies in providing a systematic review that focuses on digital transition and its intersection with S.PSS and environmental sustainability, while proposing an innovative analytical perspective. By clustering and synthesizing insights from the three reviewed areas, this perspective enables both practitioners and researchers to examine, understand and discuss how S.PSS (optimization objects) can be optimized by emerging digital technologies to pursue resulting environmental benefits (optimization effects). Furthermore, the distributed economy (DE), as a potential area of observation, is also discussed in terms of its sustainability implications within this context. The study also elucidates the role and significance of DT for S.PSS concerning environmental sustainability enhancement and identifying directions and opportunities for further research in this area.

The paper is structured as follows: Chapter 2, following introduction chapter, presents the literature background and clarifies the research questions; Chapter 3 details the research methodology; A review of the research findings and discussion are then offered in Chapter 4 and Chapter 5 respectively; In Chapter 6, a holistic conclusion is made.

# 2 Literature background

## 2.1 Digital transition and environmental sustainability

For now, there is a consensus that few studies focus on and demonstrate the links and profound implications of digital transition and sustainability in a non-isolated way (Ang et al., 2017; El Hilali et al., 2020; Mehrpouya et al., 2019). Attention is recently being drawn. It is notable, however, that fewer discussions have focused on environmental dimension of sustainability, compared with socio-ethics and the most cited economic aspects.(Sacco et al., 2021; Liu et al., 2019). Even though further research is needed, most of the scholars discussing this issue agree on that the digital transition brings more, new negative challenges to the environmental domain than positive impacts (Sacco et al., 2021).

Specifically, it is acknowledged that the material and energy consumption of ICT infrastructure (e.g. data centers) is rapidly increasing, with a consequence on heavier environmental burden (Cosar, 2019; de Sousa Jabbour et al., 2018; Lucivero, 2020). Moreover, the disposal and technical obsolescence of electronic waste (E-waste) caused by consumerism and digital penetration, with millions of tons of electronic devices discarded each year, lead to adverse health effects and environmental pollution if not appropriately handled (Aksin-Sivrikaya & Bhattacharya, 2017; Berkhout & Hertin, 2004; Kopp & Lange, n.d.; Osburg & Lohrmann, 2017). On the other hand, stakeholders' personalized demands accelerated by digital media may exacerbate unsustainability (Long, 2020).

Despite these risks, burgeoning interest surrounds the capacity of digital technologies to improve environmental sustainability. The advantages and driving forces that smart production and digital services, underpinned by digital transition, provides for business models and the environment are acknowledged (Bican & Brem, 2020; A. Q. Li & Found, 2017; Nakicenovic et al., 2019; Nascimento et al., 2018). Merdin and Ersöz (2019) contend that Industry 4.0 can offer substantial opportunities for environmental sustainability that transcend economic benefits by integrating manufacturing and business processes through digital platforms and facilitating the collaboration of sustainability initiatives (de Sousa Jabbour et al., 2018; Merdin & Ersöz, 2019). Real-time monitoring and data collection via cyber-physical systems (CPS) and the IoT can enhance energy efficiency in production processes, optimize logistics distribution, and subsequently mitigate transport-related emissions (Pyka, 2017; Thiede, 2018). AI and robotics can augment resource distribution and use, thereby curbing waste (Ghobakhloo, 2020; Stock & Seliger, 2016). Additive manufacturing (AM) enables customization and facilitates more timely, proximate production for end-users, thereby increasing resource use and helping to minimize resources and waste (Ford & Despeisse, 2016). According to estimates, digitalization may boost resource use by 25% (Kopp & Lange, 2019), and contribute to a 20% reduction in carbon emissions (Stock & Seliger, 2016).

A study by Rosário and Dias (2022) conducted a comprehensive review of the impact of digital transformation on sustainability, demonstrating the potential contribution of DT to three dimensions of environmental, economic, and socio-ethical sustainability. In terms of environmental sustainability, DT involves the application of technologies such as AI, IoT, big data analytics, social media, and mobile technologies to develop and implement sustainable urban development, environmentally friendly production and solutions management, waste management and pollution control (Bibri & Krogstie, 2016; Feroz et al., 2021). In terms of economic sustainability, emerging digital technologies can facilitate the transition to a more sustainable circular economy, digital sharing economy, and establish sustainable manufacturing and infrastructure design (García-Muiña et al., 2021; Pouri & Hilty, 2018). In terms of socio-ethical dimension, studies have shown the need for a multidimensional policy perspective to address the current digital divide (Arcelay et al., 2021; Nagano, 2019). Some other contributions are also mentioned. For example, Li and Found (2017) argue that digital platforms can facilitate the stakeholders to actively participate in the value co-creation process and contribute their data and knowledge. This enables PSS to offer individualized, demand-driven solutions (Zinke-Wehlmann et al., 2021), thereby enhancing its efficiency in terms of value creation (Tukker, 2004). Furthermore, digital platforms can directly connect buyers and sellers, while new technologies such as blockchain, distributed ledger technology, and smart contracts may enable individuals and small businesses to participate in the economy in ways never before possible, bypassing centralized organizations. This could lead to lower transaction costs, greater transparency, and new market opportunities (Čolaković & Hadžialić, 2018). However, although various advantages emerge, new challenges are also brought by DT, such as rising financial pressures and escalating technical capability requirements for the companies (González Chávez et al., 2021).

In this context, the existing literature highlights the complex and multifaceted relationship between digital transition and sustainability, especially in environmental dimension (Gürdür et al., 2019; Nakicenovic et al., 2019). But most crucially, how can S.PSS design take advantage of the digital transition to address its environmental benefits, needs to be further studied and reconsidered.

## 2.2 Sustainable product-service system (S.PSS)

As a promising approach to pursue environmental sustainability, PSS has gained attention from scholars as a strategic business-model design (Beuren et al., 2013). PSS involves a shift from the focus on selling physical products to a system of products, services, networks of stakeholders and supporting infrastructure that is more conducive to meeting ever-changing customer needs and economically competitive than traditional business models, while reducing the environmental impact of production and consumption (Cook, 2018; Goedkoop et al., 1999; Tukker, 2004). Specifically, PSS can increase the reuse, remanufacture and recycling of products at the end of life, thereby increasing resource productivity and minimizing waste generation (Ford & Despeisse, 2016). However, despite the aforementioned sustainable potential, PSS cannot be guaranteed to reduce environmental impacts unless intentionally designed (Michelini et al., 2017; Tukker, 2015; Vezzoli et al., 2014) and may even have negative impacts (Barquet et al., 2016). Thus, the concept of S.PSS has emerged, which integrates the principles of sustainability into PSS design and implementation (Vezzoli et al., 2022). Specifically, S.PSSs are models "incentivizing product-as-a-service or other models where producers keep the ownership of the product or the responsibility for its performance throughout its lifecycle"(European Commission, 2020). According to Vezzoli et al. (2021), S.PSS specifically highlights to create (new) value and decouple economic benefits from increased negative environmental impact, achieving win-win benefits. For example, Riversimple contributes to environmental sustainability by offering an all-inclusive life cycle services of a pay-per-month ownerless car. This innovative interaction between the provider and the customer increases the economic interest of the provider to design or offer long-lasting, energy-efficient, and recyclable cars.

In recent years, the discussion S.PSS has expanded to include the role of distributed economy (DE) in promoting environmental sustainability. DEs are locally based small-scale production units, shifting the control on essential activities towards or by the end-user. These local units could be stand-alone or peer-to-peer, connected with other nearby units to share various forms of products, semi-finished products, resources, knowledge/information and other types of services. On top of that, these units are sometimes organized as multiple providers to the same order, thus forming a much more resilient network. (dos Santos et al., 2021; Johansson et al., 2005; Vezzoli et al., 2018; Ranjani et al., 2021). Some scholars argue that S.PSS applied to DE (their combination) are known as promising win-win locally based and resilient sustainability approaches based on their coupling of sustainable opportunities (Vezzoli et al., 2021), and calls for further research and implementation to realize their full potential. For instance, some companies offer localized energy production systems, such as Solarkiosk, which offers home solar production systems in remote areas, which enhances the flexibility of energy production and reduces losses in the transportation of electricity over long distances.

## 2.3 Research aim and research questions

Recently, a growing number of researchers argue that DT strengthens the application of S.PSS in DE (Berkhout & Hertin, 2004; González Chávez et al., 2021; Rachinger et al., 2018). With the technical supports of DT, S.PSS develops more promising combinations with DE, and its potential toward sustainability is concurrently enhanced (Zancul et al., 2016). Shih et al. (2016) conducts an investigation delved into IoT-enabled design approaches, examining a battery replacement system for electric scooters leveraging IoT technology as the optimal solution to augment customer value. However, existing S.PSS research possesses certain limitations and focus on discrete and individual aspects. For example, Bressanelli et al. (2018) analyzed an IoT-enabled retail PSS for domestic appliances, concentrating on the manner in which IoT streamlines data for stages of usage and maintenance. Alexopoulos et al. (2018) proposed a digitally managed tool that assists the design, production, and usage planning of PSS. The core value of the tool relies on regarding PSS as an intelligent collection of physical, cyber, and organizational elements to oversee the complex management of PSS lifecycle.

In other words, the existing literature has not yet provided a holistic understanding and investigation in the impacts of DT on the implementing and dissemination opportunities of S.PSS, specifically concerning those applied to DE. Although certain viewpoints hint at the efficiency and effectiveness of digitally supported S.PSS in tackling environmental sustainability concerns, and present the potential of S.PSS applied to DE domains, some knowledge gaps remain to be filled. Consequently, this study seeks to address the following research questions: 1) Which digital technologies are mainly employed in the digital transition of S.PSS? 2) How do these digital technologies optimize (or empower) S.PSS, and what environmental benefits do they offer? 3) What opportunities and challenges emerge for digital transition in future investigations of S.PSS (and S.PSS applied to DE)?

Inconsistencies in terminology pose challenges in identifying related literature (González Chávez et al., 2021), including terms such as digital transition, digitization, Industry 4.0, and smart PSS. Therefore, this paper refrains from focusing on specific digital technologies. Instead, we examine the digital elements as an overarching theme within the digital era, encompassing a wide array of digital changes and trends to assess its association with and impact on PSS (and DE) as well as the environment. In the context of this paper, the terms digital transition, digital transformation, and digitalization are employed interchangeably, reflecting their conceptual overlap.

# 3 Methodology

Aligned with the study's objectives, we employ a systematic literature review (SLR), a qualitative research approach that aids in mitigating bias and ensures comprehensive knowledge identification due to its rigorous and methodical process of pinpointing, selecting, and critically appraising relevant studies to address the three research question (Booth et al., 2016). Information was gathered from academic literature cantered on DT, S.PSS and environmental sustainability to systematically synthesize findings and maintain transparency throughout the research process. The PRISMA checklist (Moher et al., 2009) is referenced to structure the paper.

## 3.1 Search strategy

The scientific databases used in this study comprise Scopus and Web of Science. A significant challenge in conducting literature searches is the absence of systematization and consistency in terminology. To avoid potential search omissions due to this issue, we established three keyword groups: Group A encompasses digital transition (including digitalization and various digital technologies), Group B includes (S.) PSS (and DE), along with specific terms such as system design for sustainability, and Group C focuses on environmental sustainability. All three keyword groups consist of related terms and their singular and plural forms. The search query employs the 'OR' operator within each group and the 'AND' operator to combine keywords across groups (refer to figure 1 for the final searching strings). To ensure the efficacy and richness, all types of scientific literature published from 2010 onwards were included. Ultimately, we retrieved 152 search results on Scopus and 99 results on Web of Science using the same search query.

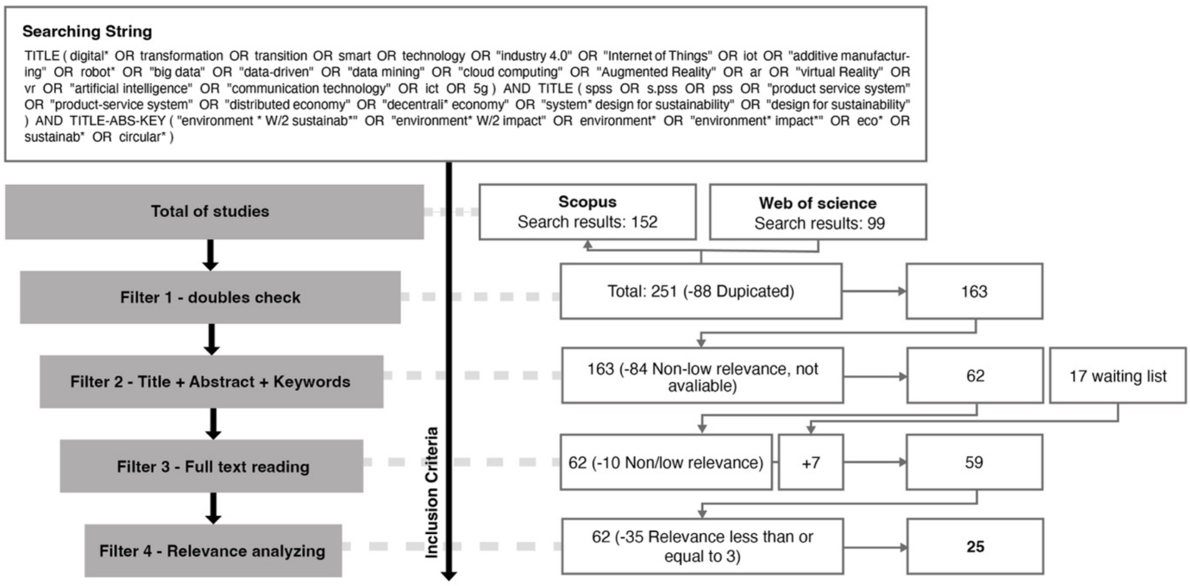


*Figure 1. Literature search procedure and results.*

## 3.2 Quality assessment and inclusion/exclusion criteria

*Table 1. Inclusion and exclusion criteria.*

| Criteria | Include | Exclude |
|---|---|---|
| **IF** has (directly or indirectly) relevant discussions of environmental dimension of sustainability. | Yes | No |
| **IF** has at least a simultaneous discussion (directly or indirectly) of the relationship between keywords from 2 groups in 3 groups (e.g. discussion of group A & B or group A & B & C). | Yes | No |
| **IF** fails to meet the last criteria, but discusses the relevant concepts (e.g. the factors influencing the implementation of (S.) PSS (and/or DE) and/or socio-technical transition). | Yes | No |
| **IF** is written in English | Yes | No |

We established a set of inclusion and exclusion criteria (table 1) and conducted four distinct screening rounds accordingly. First (Filter 1), papers from both databases were amalgamated, and 88 duplicate articles were eliminated. This considerable overlap confirmed the primary search's comprehensive coverage of highly relevant articles. Second (Filter 2), an initial screening based on Criteria 1 and 2 was performed by reviewing titles and abstracts, resulting in 62 more relevant articles. This was supplemented by 7 additional relevant articles from a waiting list of 17 articles. Upon excluding 2 articles that could not be downloaded, we obtained a total of 59 articles. In the third step (Filter 3), a full-text reading and preliminary analysis on these 59 articles were conducted (Section 4.1). Articles were subsequently categorized into 5 levels of relevance to further exclude less pertinent articles (Filter 4), culminating in a core set of 25 papers for the study.

Throughout the process, all steps—including search results, filtering stages, selected articles, and the rationale behind choices made at each stage—were carefully documented in a research log. Zotero and Endnote were employed for storing bibliographic information. The 59 articles (from filter 3) were analytically coded, following the open coding, axial coding, and selective coding process (Wolfswinkel et al., 2013). This coding process, alongside its visualization, is detailed in the subsequent section.

# 4 Results

## 4.1 Preliminary analysis

A preliminary analysis of the 59 articles obtained from filter 3 was conducted. From the overall number of search results, not many scholars have started to study this topic. Nevertheless, it unveils a distinct and growing interest in this intersectional area, as illustrated in Figure 2. (This study conducted in early 2023, the literature results of 2023 are still ongoing). Regarding the nature of contributions (figure 3), a majority of literature employed case studies (42 articles, 66%), while the literature on relevant methodologies and tools remained comparatively scarce, constituting a mere 8% and 3%, respectively. Arguably, such a distribution may be attributed to the fact that a certain number of related practice cases exist but have yet to be exhaustively studied, synthesized, and transferred into a comprehensive knowledge framework by scholars. This observation articulates the demand for further study to better inform and guide relevant practice.

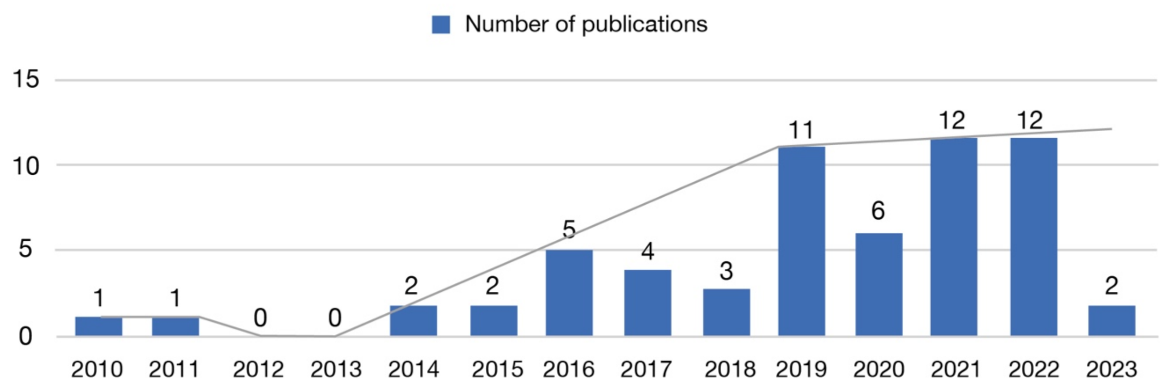


*Figure 2. Number of studies per year from the analyzed publications.*

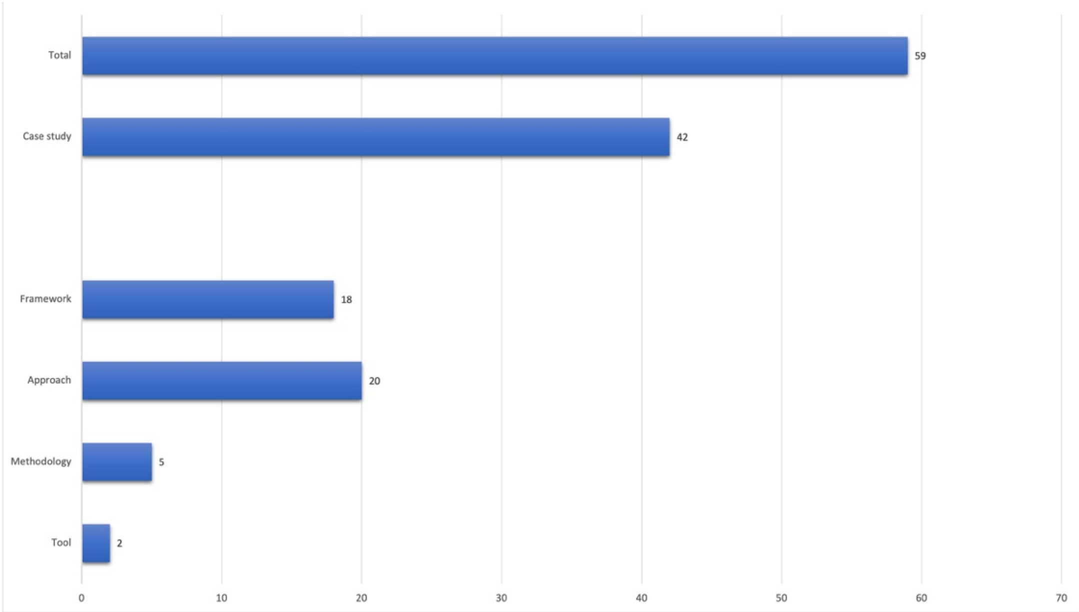


*Figure 3. Paper distribution by contributions.*

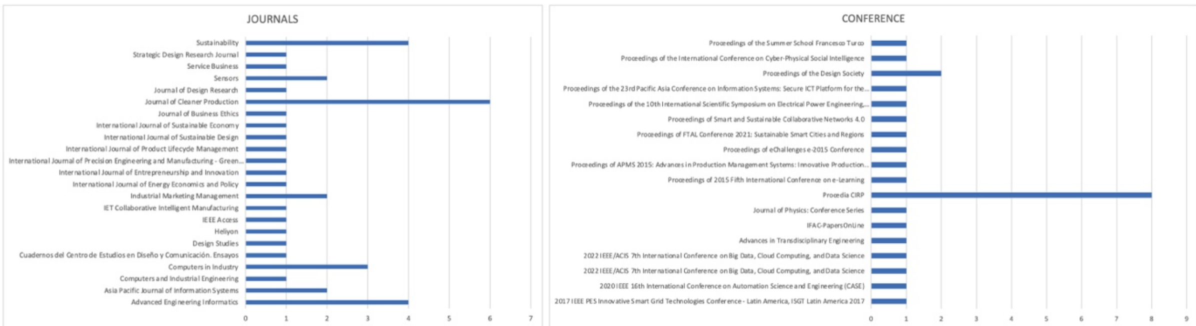


*Figure 4. Distribution of papers by journals and conferences.*

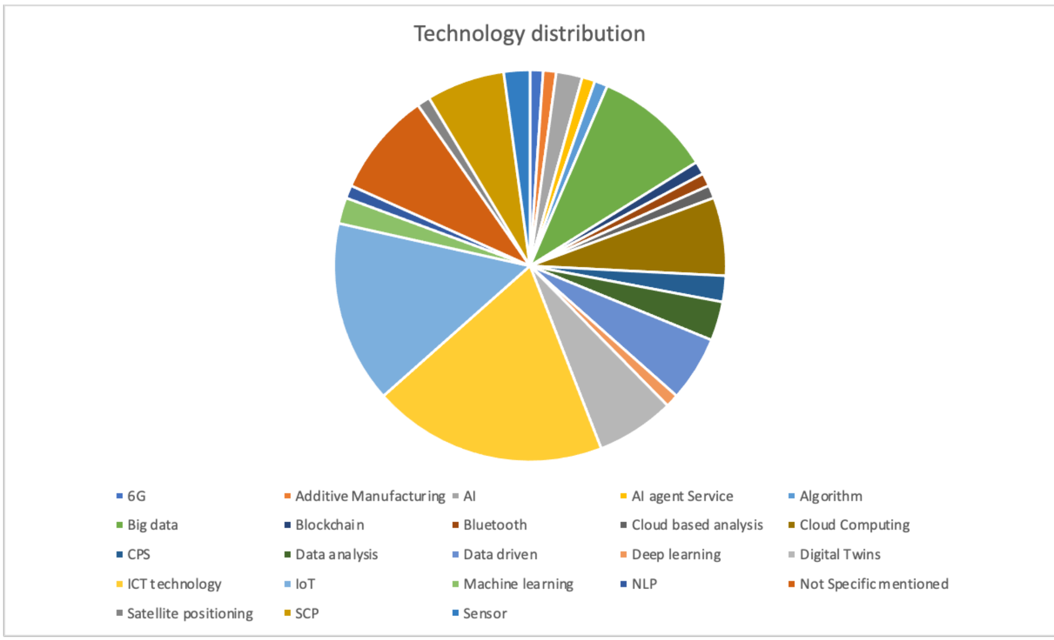


*Figure 5. Technology distribution.*

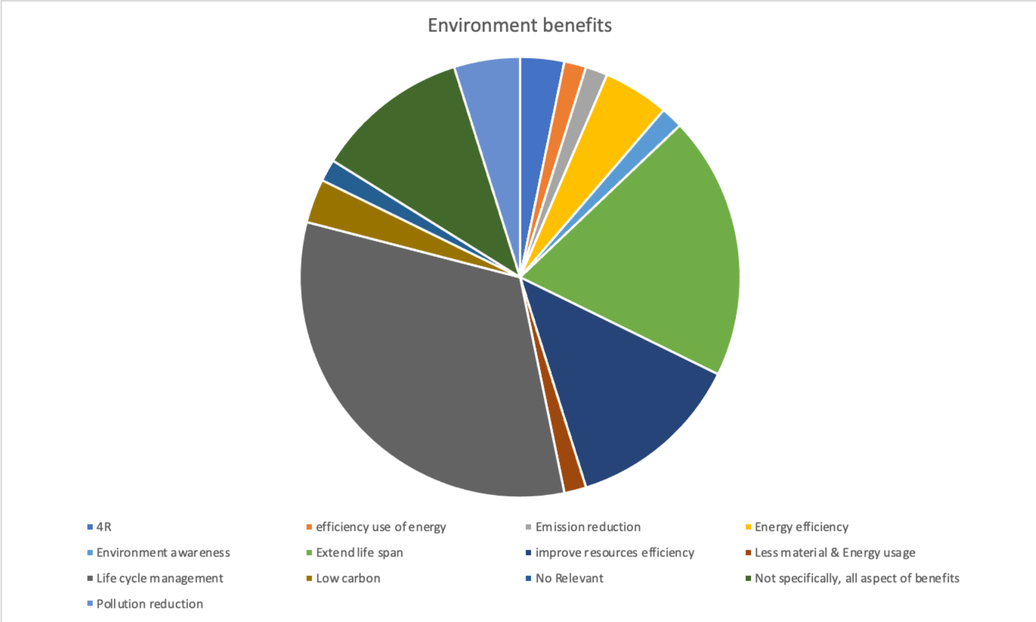


*Figure 6. (Potential) environment benefits mentioned.*

*Table 2. Classification of research themes in the literature from filter 3 ([#] codes in the appendix)*

| Case no. | DE involved | Digital technology studied | PSS related | Environmental sustainability |
|---|---|---|---|---|
| 1 | ○ | • Blockchain-, IoT- based ICT | • (Smart PSS) | ◉ (Life cycle management) |
| 2 | ○ | • AI Agent Service | • (Regular PSS) | ○ |
| 4 | • (DM) | • Data driven, IoT, Cloud computing | • (Smart PSS) | ◉ (Life cycle management) |
| 6 | ○ | ○ | • (User activity-oriented Service) | ○ |
| 7 | ○ | • Machine Learning, Data driven, | • (Smart PSS) | ◉ (Life cycle management) |
| 8 | ○ | • Big data analysis | ○ | ○ |
| 10 | ○ | • Big data, Cloud based analysis, APP sensor, SCP | • (Smart PSS) | ○ |
| 11 | ○ | • Cloud computing, SCP data | • (Product-oriented PSS) | ◉ (Energy cost reduction) |
| 12 | • (DM) | • AM, Servitising-AM | • (Regular PSS) | ◉ (Life cycle management) |
| 13 | ○ | • Big data, Deep Learning, Multi source data | • (Regular PSS) | ◉ (Life cycle management) |
| 15 | ○ | • ICT | ○ | ○ |
| 16 | • (DM) | • Big data | • (Regular PSS) | ◉ (Life cycle management) |
| 17 | ○ | • Data analysis | • (Regular PSS) | ○ |
| 18 | ○ | • Integrate ICT System (sensor, IoT, Cloud computing) | • (Smart PSS) | ◉ (Life cycle management) |
| 19 | | • Data driven, NLP | • (Smart PSS) | ○ |
| 20 | ○ | ○ | ○ | ○ |
| 21 | ○ | ○ | • (Industrial PSS [IPS2]) | ○ |
| 22 | • (DM) | • Data driven design automation | • (Data driven design automation of PSS) | ○ |
| 23 | ○ | ○ | ○ | ○ |
| 24 | ○ | ○ | • (Regular PSS) | ○ |
| 25 | ○ | ○ | • (Smart PSS) | ○ |
| 26 | ○ | • Sensor Module, IoT platform | • (Smart PSS) | ◉ (General benefits) |
| 27 | ○ | • ICT, 6G | • (Regular PSS) | ○ |
| 28 | ○ | • ICT technology (IOT, Cloud, and all Industrial 4.0 technologies) | • (Smart PSS) | ○ |
| 30 | ○ | • ICT, Sensor data access | • (Smart PSS) | ◉ (Life cycle management) |
| 31 | ○ | ○ | ○ | ○ |
| 32 | ○ | • IoT | ○ | ◉ (Life cycle optimise) |
| 33 | ○ | • IoT | ○ | • (Life cycle management) |
| 34 | ○ | ○ | • (Regular PSS) | • (General benefits) |
| 35 | ○ | • IoT based ICT, CPS | • (Smart PSS) | • (Efficiency of resources & energy savings) |
| 36 | ○ | • ICT, SCP | • (Product-oriented smart PSS) | • (Energy saving & emission reduction) |
| 38 | • (DEG) | • ICT based on remote monitoring | • (Use-oriented PSS) | ◉ (Life cycle management) |
| 39 | ○ | • ICT, AI, digital twin, IOT,CPS, Big data analytics, smart embedded system, AR/VR, etc. | • (Industrial smart PSS) | • (Life cycle management) |
| 40 | ○ | • ICT, cloud-edge computing infrastructure, software development networks, GPS | • (Smart PSS) | ○ |
| 41 | ○ | • IoT, AI, CPS | • (Result oriented PSS) | • (Architecture energy saving) |
| 42 | ○ | ○ | ○ | ○ |
| 43 | ○ | • IoT | ○ | • (Life cycle management) |
| 45 | ○ | • Data-driven, ICT | • (Smart PSS) | ○ |
| 46 | ○ | ○ | • (Smart PSS) | ○ |
| 47 | ○ | • AM | • (Smart PSS) | ○ |
| 48 | ○ | ○ | ○ | ○ |
| 50 | ○ | • ICT | • (Use-oriented PSS) | ○ |
| 51 | ○ | • Bluetooth, Automatic License Plate Identification System (ALPIS) | • (Regular PSS) | ○ |
| 52 | ○ | • ICT, IoT, Big data, Big data analytic...... | ○ | ◉ (Efficiency of resources & Life cycle management) |
| 53 | ○ | ○ | • (Smart PSS) | ○ |
| 54 | ○ | ○ | • (Smart PSS) | ○ |
| 56 | ○ | • SCP, IoT, Cloud computing, Big data analytics, Digital twin | • (Smart PSS) | ◉ (Life cycle management) |
| 57 | ○ | • Optical sorting, Automation | • (Data-driven platform-based Smart PSS) | ◉ (Efficiency of resources & e-waste lifecycle management) |
| 58 | ○ | • IOT, ICT | • (Regular PSS) | ○ |
| 59 | ○ | ○ | ○ | • (General benefits) |
| 60 | ○ | • ICT, SCP | • (Digital PSS) | ◉ (Efficiency of resources) |
| 61 | ○ | ○ | • (Regular PSS) | • |
| 62 | ○ | • Remote control (ICT) | • (Smart PSS) | ○ |
| 65 | ○ | • IoT, algorithm, digital twin, cloud, machine self-learning; satellite positioning technology | • (Smart PSS) | ◉ (Energy savings & pollution reduction) |
| 66 | ○ | • Digital Twin | ○ | ○ |
| 67 | ○ | • IoT, Big data & analytics | • (Use-oriented PSS) | • (Efficiency of resources & e-waste Life cycle management) |
| 68 | ○ | • IoT | • (Smart PSS) | ○ |
| 69 | ○ | • Digital twin, smart data acquisition sensors, data servers, big data platform | • (Smart PSS) | ○ |
| 70 | ○ | • IoT, ICT, Services and People (IoTSP), Industry 4.0) | ○ | ◉ (Efficiency of resources & Life cycle management) |

(shaded) Simultaneously focusing on DT, PSS and environmental sustainability ○ Not mentioned the specific area ◉ Mentioned the specific area ● Focus on the specific area

To further address the research questions, especially the first one, we classified the studied literature (table 2) according to the following criteria: (i) the type of digital technology, (ii) the type of (S.)PSS, (iii) the absence, mention and focus of discussing environmental sustainability, and (iv) the consideration of DE. Firstly, (i) delineates the technical emphasis of each analyzed article, while (ii) highlights the specific PSS category examined by the authors. Secondly, (iii) differentiates between literature that is unmentioned in the list, that merely mentions, or that delves into discussions of environmental sustainability, thereby facilitating further selection. Lastly, (iv) identifies articles discussing DE.

According to table 2, most of the studies explored digital technologies, with ICT technology and its affiliated IoT and SCP garnering the most interest (23 articles, 21, and 6, respectively), succeeded by 10 articles mentioned about big data technologies (figure 5). A considerable portion did not explicitly specify the technology in question but instead discussed it in general terms. Within the S.PSS categories, smart PSS emerged as the most frequently mentioned (25 articles) and evolving into a prevailing area of concern. In our analysis of 59 articles, it is noteworthy to mention that although there is a portion of mentions of sustainability benefits as additional values, a mere handful of studies (only 5 articles) explicitly focus on exploring the environment impact and its intersection with digital transition and S.PSS [#33, 35, 39, 41, 67]. This underscores the existence of a discernible research gap. In addition, few studies have focused on the contribution of DT to S.PSS in DE, and only five articles imply a positive impact of DT on diffusing distributed energy and distributed manufacturing systems. As a result, the integration of DE with S.PSS in the context of the digital transition has likewise not garnered adequate attention.

### 4.2 Systematic analysis

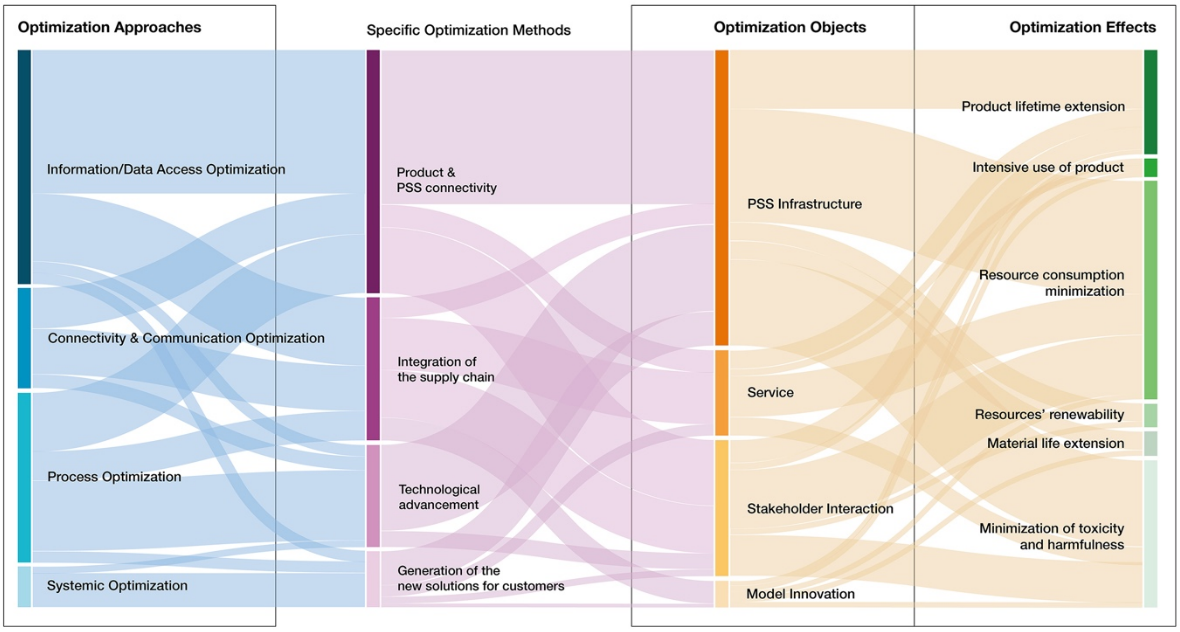


*Figure 7. An Inductive perspective on existing influencing mechanism of DT, S.PSS and environmental benefits.*

The existing studies share a general agreement that DT holds the potential to empower S.PSS and contribute to positive environmental impact. However, the underlying mechanisms through which DT drives these impacts on S.PSSs are still scattered and not systematically understood. We, therefore, further select 25 more relevant articles (filter 4) for conducting a more in-depth and systematic analysis in order to address the second research question. Specifically, we summarize the optimization approaches of DT on S.PSS that are extracted from existing studies and cluster them into four (general) categories (namely, Information/Data Access, Connectivity & Communication, Process, and Systemic Optimization). Specifically, the interpretation of these approaches is as follows:

- Information/Data Access Optimization is a vital and foundational approach to enhances the ability to obtain information and/or data in specific S.PSS phases, such as design and management, where digital communication technologies (e.g., IoT sensors) can be simply integrated to optimize monitoring, tracking, collecting, and reporting of pertinent data, e.g., quality and performance metrics of physical objects/products (Basirati et al., 2019b). It is also seen as an interface for transferring information from the physical world to the cyber one. For example, in Case #1, the integration of IoT and blockchain technologies digitalizes the prefabricated components in prefabricated housing construction, allowing for digitally parametric adjustments within Building Information Modelling (BIM) systems. This approach aimed to reduce material consumption and enhance usage efficiency. #70 presents a case study in which Microsoft reduced energy consumption by 30% in a building by implementing an IoT, Services, and People (IoTSP) building control platform. This highlights the environmental benefits brought about by more efficient energy consumption data and intelligent monitoring services, empowered by digital technologies [#35 & #41].
- Connectivity & Communication Optimization emphasizes the optimization of connectivity and communication within S.PSS, facilitated by digital information as the enabling medium (particularly in stakeholder interaction and service dimensions of S.PSS). It encompasses the integration and coordination of/among both devices and stakeholders. For instance, Case #67 highlights the capacity of ICT to create an intelligent, interoperable organization of household products with other products or devices. This approach enables targeted digital control and software upgrades for home consumables, thereby minimizing resource consumption and extending product lifetime (Porter & Heppelmann, 2014). Case #36 illustrates how ICT-based connectivity streamlines shared information links and interactions between products and customers or service providers. This enables users to remotely access usage and energy consumption data for devices such as smart lamps or air conditioners and control them from a distance (Liu et al., 2020). Users can even avert unnecessary resource waste by promptly accessing energy consumption or product status, facilitating maintenance before significant damage occurs (Basirati et al., 2019b; Gaiardelli et al., 2021).
- Process Optimization constitutes a critical stage of transforming the collected data, this approach employs information processing-oriented technologies, such as cloud computing and data analytics, to streamline the process. It can analyze data and control certain PSS processes with a certain degree of pre-defined autonomy and self-analytic/diagnostic capabilities. For example, Elia et al. (2016) examined a waste-collecting PSS solution that incorporates IoT and highlighted its superiority over conventional waste-collecting methods, due to its increased data processing efficiency. Similarly, Case #39 presents a case study of battery waste management to illustrate the enhancement of technologies, such as data analytics, on the life expectancy and recycling effectiveness of products, as well as the overall service processes in PSS (Zheng et al., 2019, 2020).

- Systemic Optimization, as systemic level, is a more sophisticated, all-encompassing and holistic approach to PSS. By using more advanced analytical and intelligent techniques (e.g., big data analytics and AI), systemic optimization aims to thoroughly upgrade the underlying back-office management systems (Barbosa et al., 2016; Papakostas et al., 2016) and decision-making capabilities of PSS (Wuest et al., 2018) in a deeper way, potentially solving macroscopic and complex issues. For instance, researchers in Case #4 consider cyber-physical resources as a whole and create a smart circular system that discusses the key features in sustainable smart PSS development.

Subsequently, through further in-depth screening and analysis of 25 core articles, it was discovered that the aforementioned four types of optimization approaches point to four different PSS objects based on the fundamentally constitutive elements of PSS (Mont, 2002; Vezzoli et al., 2021): Infrastructure , Service , Stakeholders interaction and PSS business model. The optimization on infrastructure encompasses both products and small-scale production units; Service includes information platforms, comprehensive services, and after-sales support; Interaction pertains to the means by which information flows are transmitted among various stakeholders and infrastructures in PSS, encompassing user experience and the upgrading and iteration of such experiences; Business models innovation primarily describe the operational methods and value of PSSs.

The matching process of optimization approaches and optimization objects reflects how digital technologies optimize PSS and provide environmental benefits, which addresses the second research question, and details (showed in figure 7) are given on the proportion of different aspects mentioned in the 25 analysed literature. According to figure 7, despite the four DT optimized objects, in practice, the existing discussion predominantly concentrate on optimization of PSS infrastructure. Specifically, the implementation and enhancement of these technologies primarily focus on physical product service, maintenance, transportation, and disposal [#4, 12, 26, 30, 41, 39, 70], as well as stakeholder interaction [#11, 33, 36, 38, 39, 70].

Lastly, by identifying, summarizing, and clustering the environmental benefits of the optimized objects in the literature, we discovered that digital technologies specifically enhance the sustainable performance of PSS in six areas: Product lifetime extension, Intensive use of product, Resource consumption minimization, Resources' renewability, Material life extension, and Pollution reduction.

Among them, lifecycle-related optimization （e.g. product and material lifetime extension）emerges as one of the most frequently cited aspects of potential environmental benefits, with 70% of studies mentioning digital technologies as optimizing and improving the associated production and PSS lifecycle management, which presents a highly potential avenue for facilitating S.PSS design and implementation. For instance, in cases #04, 12, 13, 30, 35, 39, 69 and 70, numerous technological optimizations are focused on digitizing and parametrizing infrastructure that acts as a carrier and employing algorithms to manage the product lifecycle more efficiently and intelligently. This encompasses the entire PSS lifecycle from the initial stages, e.g., computer-aided design (Komoto & Tomiyama, 2008; Marilungo et al., 2017) and digital twins to minimize the consumption of physical resources for design and testing (Basirati et al., 2019a; Goto et al., 2016), to the incorporation of service domains (Basirati et al., 2019b; Bressanelli et al., 2018; Marilungo et al., 2017; Rymaszewska et al., 2017). Furthermore, several studies have discussed connectivity optimization, which encompasses the coordinated collaborative capabilities facilitated by information sharing between devices and stakeholders, thereby improving production and service efficiency of PSSs [#67], meeting dynamic demands (Gaiardelli et al., 2021; Thoben et al., 2017), as well as enabling stakeholders to readily access cyber-physical resources to support sharing, reuse, remanufacturing, and recycling in a sustainable manner [#39]. The optimization of interaction has also enabled significant resource and energy savings for users or service providers in terms of remote control of products [#33, 36, 39, 67, 70]. For instance, in case #11, 16, 26, 33, 38, 41 and 67, the real-time monitoring and remote access and (automatic) analysis of product data enhance the accessibility and maintenance services by improving the failure control capability of S.PSS, and ensure the preventive and/or predictive maintenance services to extend the lifetime of product and material (Bressanelli et al., 2018; Lerch & Gotsch, 2015; Eldegwi et al., 2016), and remote maintenance to reduce the carbon footprint caused by on-site services (Sassanelli et al., 2022).

Besides, approximately a quarter of the studies address efficient or low-energy usage, not only on the production side, but also through the optimization of services or PSS models to regulate the use or saving of energy or material. Some isolated studies make brief references to pollution reduction through digital technologies [#18, #41] and raising public awareness about sustainability. Additionally, Cook (2018) studied a smart bike-sharing system that changed user behavior through services supported by a digital platform, which aimed to reduce energy consumption and pollution caused by car travel.

From this synthesis, it is arguable that, although the majority of existing studies indicate the environmental advantages contributed by digital technologies, these contributions appear relatively homogeneous. Because they mostly focus on lifecycle extension [#4, 12, 30, 33, 39, 44, 50, 56, 57, 60], minimizing consumption /efficient use of resource and pollution reduction, or minimization of toxicity and harmfulness [#33, 35, 36, 38, 39, 41, 50, 52, 56, 57, 60, 65, 70]. On the other hand, there is certain discourse on other aspects, such as resource renewability [#33, 56, 57, 60] and increased product use intensity [#11, 50, 60]. For instance, #60 presents a smart car sharing and renting system (car2go) that, with the support of ICT, reduces the environmental impact of vehicles by increasing the usage efficiency and intensiveness of cars and promoting the adoption of electric cars (renewable energy) through digital interactions with customers.

Additionally, although digital technologies have been employed to optimize various types of PSS (Marilungo et al., 2017; Basirati et al., 2019), no evidence within the 25 core articles suggests that these optimizations directly enhance the sustainability of DE. Nevertheless, A handful of cases [#4, #12, #16, #22, #38] exemplify the considerable potential of DT to contribute to sustainability in specific areas of DE. For example, case #38 highlights the potential of ICT to support the deployment of distributed home energy generation systems (solar energy) in remote areas. Case #12 investigates the relation between Additive Manufacturing (AM) and PSS according to different and interdependent categories pertaining to lifecycle, service orientation and customer proximity.

# 5 Discussion

Drawing upon the systematic analysis of existing literature, several prospective research directions can be discerned to address the third research question. Firstly, the potential of improving sustainable benefits by digitally supported S.PSS has been mentioned by a portion of scholars, but research that focuses on uncovering the intersection and nexus among the three focused areas (DT, S.PSS and environment sustainability), especially in answering how S.PSS can be influenced by DT to further consider environmental impacts, presents a notable gap. This is in line with the views of Li and Found (2020), who argue that, despite the win-win potentials (Vezzoli et al., 2021), enterprises (producers or providers) adopt environmentally sustainable solutions primarily incentivized by economic values. Although environmental values do arise from the digitally technology-driven S.PSS transformation, they are often the least considered drivers and are more often seen as a "byproduct". Therefore, considering the emerging risks caused by DT, there is an urgent need for further concentrated inquiry in this intersectional area. Concerning research contributions, we suggest strengthening the development of relevant pilot projects and knowledge-base (conceptual frameworks and theories) to facilitate a more comprehensive understanding of S.PSS's new role in promoting environmental sustainability in the digital era. Likewise, an emphasis should be placed on enhancing methodologies and tools to guide businesses in their practices. Secondly, regarding research content, the majority of current studies focus on the relatively fundamental aspects of digital technologies (information access and process optimization approaches), to enable (production-related) infrastructure of S.PSS. An obvious paucity of discussions on the systemic optimization capacity and approaches for digital transition is evident. We thus strongly recommend further investigation into the applications and studies that augment the profound, comprehensive, and systematic intervention of digital technologies in S.PSS, specifically in the realm of business model and value proposition innovation. Because such systematic innovations hold significant potential to catalyze deeper change and facilitate the upgrading of existing socio-technical systems (Ceschin, 2014). In terms of emphasizing environmental benefits, the existing literature focuses on efficient use of/resources consumption minimization and pollution (toxicity and harmfulness) minimization. Therefore, research on other environmental aspects through digital-facilitated S.PSS, especially on promoting resources renewability or biodegradability (e.g., materials or energy), as well as resource recovery (material lifecycle extension), deserves further attention, as these areas are currently underexplored. Moreover, although this study focuses on discussing how DT influences S.PSS and its associated environmental performance, DE is still investigated as a significantly potential area for observation, considering the heightened sustainable benefits of integrating S.PSS and DE, argued by Vezzoli et al (2021). However, given the notable absences of academic investigation regarding the impact of DT on DE, and its integration with S.PSS, we underline the importance of incorporating DE more extensively into relevant research.

The limitations of this study warrant discussion. Firstly, we emphasize the support DT provides for S.PSS in terms of environmental performance. However, associated negative effects (new barriers) are not adequately addressed due to insufficient literature on this subject. The qualitative approach based on literature research may also constitute a limitation. Because the limited literature may have led to some limitations in understanding the current state in this paper, necessitating further development and validation of our proposed viewpoints that relate to optimization of DT, S.PSS relevant objects, and environmental benefits through the analysis and summary of practice within the context of case studies. Moreover, certain results still require quantitative verification, such as calculating the environmental benefits and the extent of technology involvement in PSS, which will be addressed in the future.

In fact, the mechanisms through which DT affects S.PSS and its sustainable performance are complex and diversified, necessitating more in-depth examination in various aspects, such as direct/indirect impacts, differing degrees, and technology limitations. Further investigation is required to enrich our proposed analytic perspective, elucidating the dynamics of DT on S.PSS, particularly regarding design and diverse environmental impact. Additionally, our limited search results hinder a comprehensive examination of DE. This may be attributable to the absence of specified keywords in the search string, such as distributed design or distributed food production. Considering the remarkable potential of integrating PSS with DE, we intend to explore this aspect more intently in the future. Lastly, as this study predominantly answered how DT influences S.PSS, investigation that concentrates on how S.PSS can influence sustainable digital transition through design, especially in addressing environmental issues arising from DT, merits further.

# 6 Conclusion

Through a systematic review, this study delivers an analysis, categorization, and summary of the foundational structure of approaches, facilitating a preliminary but holistic understanding of current advancement and how could DT potentially impact S.PSS and environmental benefits, the relationship between DE within it, and a description of recommendations for future research. The key findings of this paper include: (i) observing that research on the relationship between DT, S.PSS, and the environment, although it is lacking, is on a growing trend. Although it is perceived and mentioned by many scholars, the studies that focus on explore the pathways and capabilities of DT for promoting environmental sustainability of S.PSS (and DE) remains relatively limited and nascent. Moreover, much of the existing research focuses on the value of digital technologies in relation to product production and lifecycle management and efficient use of resources, which hints at the potential contribution of DT to S.PSS, but ignores other sustainable aspects. (ii) A novel perspective is employed to summarize the existing literature concerning DT optimization approaches for S.PSS relevant objects, and environmental benefits. This enables the realistic identification of digital transition's potential to contribute to environmental performance by empowering S.PSS. The emphasis and shortcomings of relevant research are discerned, and corresponding research directions are suggested. In terms of DT optimization approaches, research on connectivity and systemic optimization should be paid more attention, compared with information access and process optimization; regarding optimization S.PSS objects , a gap exists in focusing on how DT can contribute to innovation in S.PSS value chains, services, and model, necessitating further investigation; concerning optimization results (environmental benefits), minimization of resources consumption and pollution reduction receive the excessive concentration of attention, while other aspects, such as resource renewability and product intensive use, have been too little addressed, demand further exploration. These findings provide a state-of-the-art perspective on research, expanding inspiration and knowledge about the intersection of the three domains, while also highlighting future priorities for essential research. Through a systematic review, this study addresses the aforementioned gap, paving the way for S.PSS to accelerate the societal transition toward digital sustainability, transforming digital transition into an enabler rather than an obstacle.

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## Appendix

| #Case | Article Title | Author(s), Year |
|---|---|---|
| 1 | A blockchain- and IoT-based smart product-service system for the sustainability of prefabricated housing construction | (C. Z. Li et al., 2021) |
| 2 | A Case Study on the Continuous Usage Intention of Artificial Intelligence Speaker in Product Service System Perspective | (Yoon et al., 2022) |
| 4 | A data-driven reversible framework for achieving Sustainable Smart product-service systems | (X. Li et al., 2021) |
| 7 | A machine learning-based iterative design approach to automate user satisfaction degree prediction in smart product-service system | (Cong et al., 2022) |
| 11 | A user-centric smart product-service system development approach: A case study on medication management for the elderly | (Chang et al., 2019) |
| 12 | Additive Manufacturing and PSS: a Solution Life-Cycle Perspective | (Zanetti et al., 2016) |
| 13 | An Advanced Operation Mode with Product-Service System Using Lifecycle Big Data and Deep Learning | (Ren et al., 2022) |
| 16 | Big Data Supported PSS Evaluation Decision in Service-Oriented Manufacturing | (L. Li & Mao, 2020) |
| 18 | Conceptual Modeling of Extended Collision Warning System from the Perspective of Smart Product-Service System | (Wu et al., 2022) |
| 26 | Development of a Smart Connected Product-Service-System (PSS) for the Waste Management Ecosystem | (Barth et al., 2021) |
| 30 | Environmental Assessment Methods of Smart PSS: Heating Appliance Case Study | (Maliqi et al., 2022) |
| 33 | Exploring Opportunities of IoT for Product–Service System Conceptualization and Implementation | (Basirati et al., 2019a) |
| 35 | From Linear to Circular Economy: PSS Conducting the Transition | (Michelini et al., 2017) |
| 36 | How sustainable is smart PSS? An integrated evaluation approach based on rough BWM and TODIM | (Liu et al., 2020) |
| 38 | Improve sustainability of decentralized energy using product service system based on ICT | (Eldegwi et al., 2016) |
| 39 | Industrial smart product-service system development for lifecycle sustainability concerns | (Zheng et al., 2020) |
| 41 | Industry 4.0 Driven Result-oriented PSS: An Assessment in the Energy Management | (Sassanelli et al., 2022) |
| 50 | Product service system innovation in the smart city | (Cook, 2018) |
| 52 | Product-service systems evolution in the era of Industry 4.0 | (Gaiardelli et al., 2021) |
| 56 | Smart product-service systems: A novel transdisciplinary sociotechnical paradigm | (Hiekata, 2019) |
| 57 | Social Implications of Introducing Innovative Technology into a Product-Service System: The Case of a Waste-Grading Machine in Electronic Waste Management | (Taghavi et al., 2015) |

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| 60 | Sustainability and competitiveness through digital product-service-systems | (Kölmel et al., 2016) |
| 65 | The design of an IoT-based route optimization system: A smart product-service system (SPSS) approach | (Shao et al., 2019) |
| 67 | The role of digital technologies to overcome Circular Economy challenges in PSS Business Models: An exploratory case study | (Bressanelli et al., 2018) |
| 70 | Towards Sustainability: PSS, Digital Technology and Value Co-creation | (A. Q. Li & Found, 2017) |