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The Role of Digital Servitization in driving Sustainability: A Systematic Literature Review

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ABSTRACT:
This study aims to examine the role of digital servitization in driving sustainability by integrating insights from the existing literature. Notably, the study seeks to identify how digital servitization enables sustainability through its antecedents, processes, and outcomes. This systematic literature review forms the core methodology, analysing 52 peer-reviewed articles selected from Elsevier's Scopus database using well-defined criteria. This process ensures a comprehensive understanding of the relationship between digitally-enabled servitization and sustainability. The study develops an integrative framework that categorizes the findings into three key components: antecedents, the sustainable digital servitization process, and outcomes. Antecedents include technological, organizational, strategic, customer-centric, and market and environmental elements, all driving digital servitization. The process is structured into key elements such as Business Model Innovation and Value Creation, Technology Integration and Digital Transformation, Service Design and Customer-Centric Innovation, Digital Ecosystem Collaboration and Supply Chain Transformation, Sustainability and Circular Economy Integration. These processes result in diverse outcomes, including operational efficiency and financial performance, enhanced collaboration and ecosystem synergies, social sustainability and human development, and environmental sustainability and circular economy outcomes. A linkage-exploration review matrix is created to visualize and analyse the relationships among these components. This matrix maps the connections and emphasizes gaps in the literature, like limited focus on social sustainability and the need for industry-specific exploration. Findings reveal that digital servitization significantly contributes to sustainability by leveraging digital technologies to optimize resource use, reduce waste, and foster collaboration across ecosystems. Theoretical contributions include the development of a framework that provides a holistic understanding of the sustainable digital servitization process. From the managerial perspective, the study offers actionable insights for leveraging digital tools to achieve sustainability goals, improve ecosystem synergies, and foster innovation. Limitations include reliance on a specific database and the challenges of synthesizing diverse research methodologies. Nonetheless, the findings cover the way for future research opportunities, including AI integration for sustainable supply chains, customer involvement in driving sustainability and circular practices, the impact of real-time customer feedback on sustainable business models, the influence of external markets and regulatory pressures on business model innovation, and technological integration in sustainable business models. This study serves as a foundational resource for academics and practitioners, advancing understanding of how digital servitization can enable sustainability and addressing critical gaps in the literature.

KEYWORDS: Digital Servitization, Sustainable Digital Servitization, Sustainability, Triple bottom line, Smart Product-Service Systems, Circular Economy, Systematic Literature Review

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1 Introduction

This chapter provides a comprehensive overview of the study, including the background of digital servitization fostering sustainability and the research objective of the study. It also highlights the identified research gap and motivation for exploring the role of digital servitization in enabling all dimensions of sustainability: economic, environmental, and social. Lastly, it describes the structure of the thesis.

1.1 Background

Digital Servitization is a rapidly growing strategy for manufacturing firms, offering services throughout a value chain. Product-centric companies are leveraging digital tools to streamline service delivery and boost the value of their combined offerings. This increases the value of their product-service offerings and requires changes to the processes and business models (Candell et al., 2009). Digital servitization is a shift from physical goods to service-based offerings powered by information and communication technologies (Lenka et al., 2017).

Scholars provide various perspectives on digital servitization. For example, Porter and Heppelmann (2014) highlight that digital servitization is not just about the individual elements but the comprehensive approach that creates value by combining products, services, software, and analytics. Vendrell-Herrero et al. (2017) define digital servitization as the business model approach that utilizes digital technologies to enrich existing non-digital goods and services, while Opresnik and Taisch (2015) emphasize the role of big data in creating and delivering services for the competitive edge.

By combining servitization with digitalization, companies can achieve several benefits that lead to greater performance, like a stronger competitive advantage, increased customer satisfaction and retention, new revenue streams, improved operational efficiency, and sustainability. In addition, embracing digital technologies contributes to a greener economy by enabling the eco-friendly production processes, communication channels, and products, ultimately enhancing economic value (Opazo-Basáez et al., 2018).

Through digital servitization, businesses can use data analytics, IoT, and AI to offer remote monitoring, predictive maintenance, and other cutting-edge services that raise customer happiness and product value (Kohtamäki et al., 2021). Furthermore, digital servitization can significantly lessen its adverse environmental effects by maximizing resource utilization, cutting waste, and advancing circular economy ideas (Reim et al., 2015). Digitally enabled predictive maintenance, for instance, can decrease an overall carbon footprint by extending the life of machines, reducing downtime, and reducing the need for replacement parts (Porter & Heppelmann, 2014).

Sustainability in digital servitization involves strategically integrating digital technologies and servitization practices to promote environmental, economic, and social sustainability in manufacturing and service-oriented organizations. Advanced data analytics and artificial intelligence (AI) can optimize production processes, reducing costs and environmental effects (Sjödin et al., 2023). Product-as-a-service arrangements, in which customers pay to use things rather than own them, push producers to create long-lasting and recyclable products (Baines et al., 2017).

In modern times, where energy is depleting faster than regenerated, and humans are facing an imminent energy crisis, another advantage of digital servitization is increased energy efficiency; smart grid integration enables manufacturers to manage energy use better and employ renewable energy sources, lowering greenhouse gas emissions (Opresnik & Taisch, 2015). Advanced energy monitoring systems enable businesses to track and optimize their energy use in real-time, resulting in significant energy savings.

1.2 Motivation for the study

The literature on sustainable digital servitization is ever-growing; however, specific gaps still require further investigation and research. Most research focuses on sustainable practices in conventional industrial settings (Baines et al., 2017) or digital servitization's commercial and technological aspects (Kohtamäki et al., 2021; Lenka et al., 2017). Despite the growing understanding of the link between digital servitization and sustainability, a well-defined framework is needed to demonstrate sustainability-related outcomes of the digital servitization process. In response to this need, this study presents a systematic and critical review of the literature on sustainable digital servitization, aiming to synthesize insights on how digital servitization enables sustainability by identifying the antecedents, processes, and outcomes of digitally enabled sustainable servitization.

1.3 Research Objective

This research study aims to synthesize insights on how digital servitization enables sustainability. Integrating existing research and connecting the insights from various studies contributes to digital servitization literature. It also offers scholars and practitioners a clear understanding of the digital servitization process, its mechanism, and its sustainability benefits. It involves the selection, reading, and analysis of 52 articles, resulting in the development of an integrative framework, following a similar approach used by Rajagopalan (1993) in their work on the strategic decision processes and by Hutzschenreuter and Kleindienst (2006) in their research on strategy-process studies.

This framework demonstrates how certain elements (antecedents) drive digitally enabled sustainable servitization, outlines the process, and highlights outcomes. Linkages among the elements (antecedents, process, and outcomes) have been identified by reviewing the established digital servitization research. This approach aligns with what Pettigrew (1997) describes as processual research, which seeks to understand the evolving relationships within complex processes.

1.4 Thesis Structure

The thesis has been divided into five chapters. The first chapter introduces the study, including the background, research gap, motivation for the study, and research objective. Additionally, it explains the thesis structure. The second chapter describes the methodology and selection criteria used to identify the previous literature from digital servitization. The third chapter, development of the framework, develops an integrative framework and a linkage-exploration matrix. The fourth chapter, the literature review, examines the existing literature with the help of the developed integrative framework and examines the interrelation between antecedents, processes, and outcomes of digital servitization, concluding with an overall evaluation. The conclusion chapter discusses future research opportunities, theoretical and managerial implications, and limitations.

2 Methodology

This study provides systematic literature to identify how digital servitization enables sustainability. Systematic literature reviews are among the most proficient and high-quality ways to identify and assess the extensive literature (Mulrow, 1994). This systematic literature review is designed to be well-structured and objective as per the guidelines of David and Han (2004) and Newbert (2007). Hence, it ensures the systematic understanding of the existing literature on digitally enabled servitization fostering economic, social and environmental sustainability. This comprehensive search was conducted using Elsevier's Scopus database to categorize the relevant literature.

Scopus was selected as the database for this review as it is recognized for indexing high-quality, peer-reviewed publications, including journal articles, conference papers, and books (Martín-Martín et al., 2018). Furthermore, a search query was developed to identify various digital servitization and sustainability studies. The first set of keywords consists of terms such as "digital servitization", "digital service innovation", "product, service, software*", and "smart product-service system*", reflecting the study's focus on digital servitization. In contrast, the second set of keywords was related to sustainability terms such as "sustainab*", "circular*," "regenerati*," "triple bottom line," and "sustainability-oriented" (see Table 1).

Table 1. Overview of Search Keywords

Database	**Elsevier's Scopus**
Search Query	(TITLE-ABS-KEY ("sustainab*" OR "circular*" OR "regenerati*" OR "for sustainability" OR "triple bottom line" OR "sustainability-oriented" OR "Circular(ity)-oriented" OR "green") AND TITLE-ABS-KEY ("digital servitization" OR "digital servitisation" OR "digital service innovation" OR "product, service, software*" OR" smart product-service system*"))

A wildcard (*) was used to ensure variations of key terms were included, like "sustainability" and "sustainable," enhancing the comprehensiveness of the search. The Boolean operator "AND" was used to connect the digital servitization and sustainability keywords, ensuring that the search results include studies addressing both topics. This approach reflects the search strategy for systematic reviews employed by Lightfoot et al. (2013) in their review of servitization, where a broad yet focused search helped ensure comprehensive coverage of relevant studies. The search query was applied to the title, abstract, and keywords fields in Scopus to get the initial result.

The defined query resulted in 120 articles. These articles were then checked for relevance to the subject of this study by reviewing the title and keywords, which resulted in 54 relevant articles. Subsequently, the abstracts of the remaining articles were read to find more articles related to digital servitization and sustainability. As a result, an additional 17 articles were found relevant. Articles not primarily focused on social or environmental sustainability were eliminated.

Additionally, 19 articles were removed due to access limitations. The final sample consisted of 52 articles in English that met all inclusion criteria, ensuring the selected literature provided a focused perspective on digital servitization enabling social and environmental sustainability. Of these, 25 articles had JCI scores ranging from 7.3 to 12.9, another 16 had scores between 3.3 and 6.6, and the remaining had scores from 1.4 to 2.5, representing publications in top-tier journals with significant impact. Search results from the database and sample numbers can be seen in Figure 1 below.

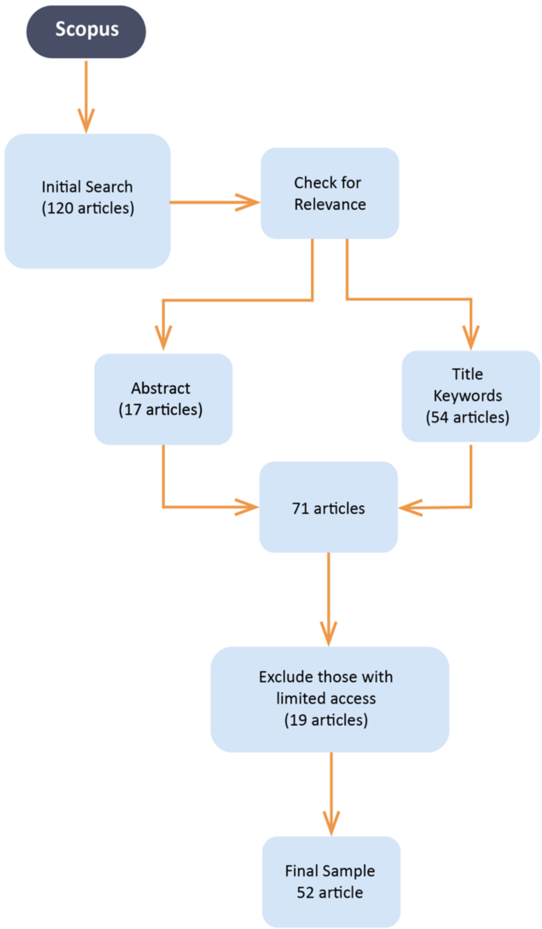


Figure 1. Search results from the database

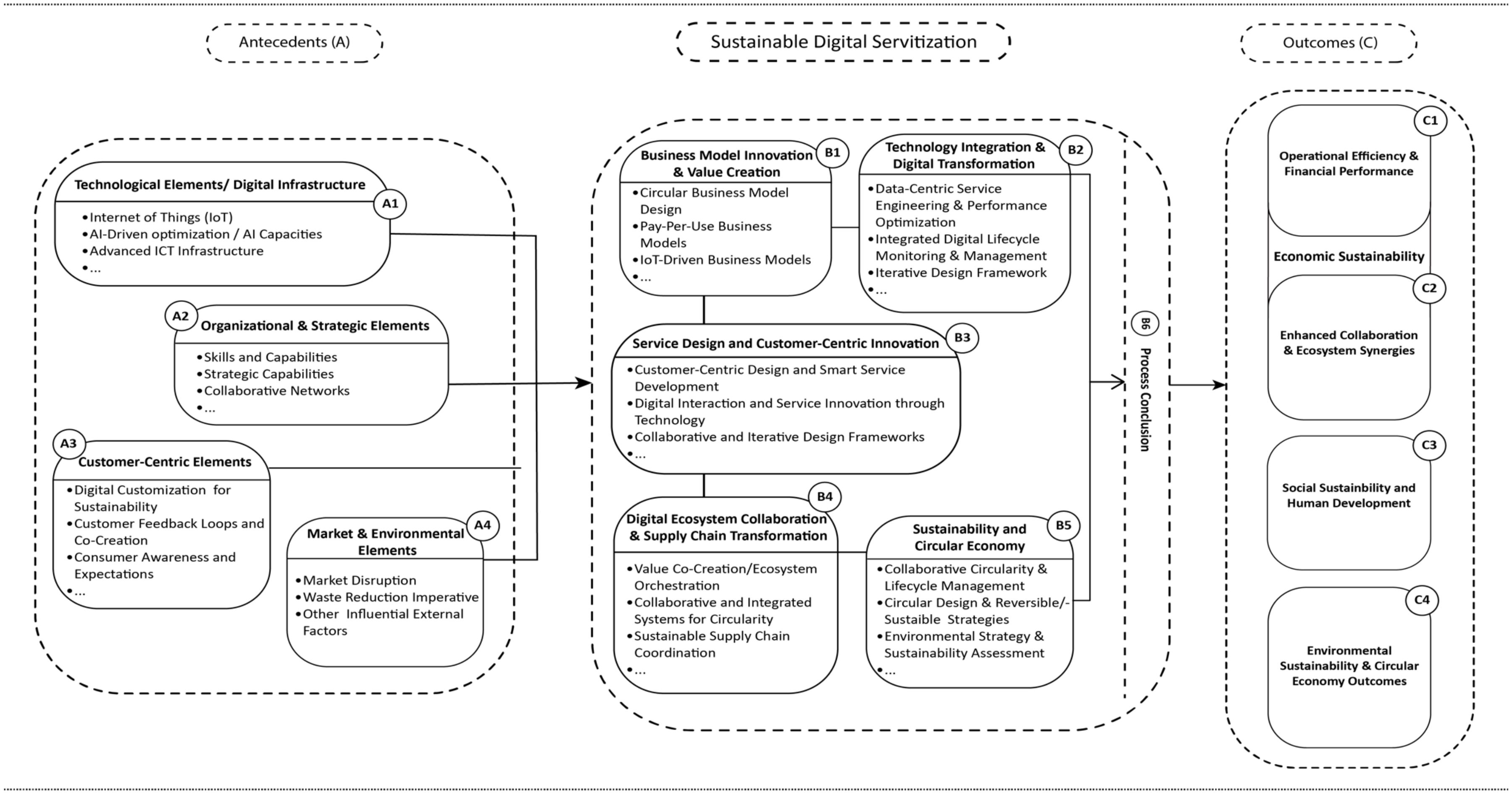
After this, all the articles were downloaded and read thoroughly to identify various elements, and a framework was structured by categorizing those elements into antecedents, processes, and outcomes of digital servitization. While grouping the outcomes elements, the main focus was on social and environmental sustainability. This framework helped to synthesize the previous research, highlighting the interconnectedness of key factors in digital servitization. Subsequently, a linkage review matrix was developed by comparing and aligning the elements of our integrative framework. This methodology ensured a rigorous and comprehensive approach to examining digital servitization in sustainability, carefully examining relevant elements, methodological transparency, and analytical depth.

3 Development of Framework

This study builds on the systematic literature review concerning the digital servitization that contributes to social and environmental sustainability. Finally, all the articles included were carefully reviewed to understand their relationship while extracting data on study type, sample size, sample characteristics, industry type and key empirical findings. It has been a very important step in the process of establishing the integrative framework. Through a careful analysis of the results, a categorization like the one proposed by Hutzschenreuter and Kleindienst (2006) was observed and applied. This study systematically identified and selected relevant elements from the sample of 52 articles to develop a comprehensive framework for sustainable digital servitization. Each element incorporated into the framework reflects insights derived directly from these selected articles, ensuring the framework is grounded in established research.

Consequently, three overarching categories of the elements relatable to digital servitization were identified: antecedents to the processes (A), the digital servitization process itself (B), and outcomes of the whole process (C). This approach ensures that the framework is comprehensive and represents current knowledge based exclusively on the identified literature sample. Afterwards, a linkage-exploration matrix was developed, in which rows represent the independent elements and columns represent the dependent elements, explaining the impact of one set of elements on another, for instance, the impact of Technological elements/digital infrastructure (A1) on Business model innovation and value creation (B1). A two-digit key (01-52) was used to code the studies. Each study that explored a linkage was placed within the corresponding section of the matrix. This chapter provides a concise overview of the identified categories of elements related to digital servitization, accompanied by the integrative framework (see Figure 2), and a linkage-exploration review matrix (see Figure 3).

Figure 2. Integrative Framework of Sustainable Digital Servitization



3.1 Antecedents (A)

In sustainable digital servitization, antecedents are the initial drivers enabling or affecting the company's transition from the product-centric model to a service-oriented, digitally enhanced business model. The detailed analysis of the selected literature has identified four distinct categories of antecedents specifically relevant to sustainable digital servitization: technological elements/digital infrastructure, organizational and strategic elements, customer-centric elements, and market and environmental elements.

Each category comprises specific enablers supporting and enhancing sustainable digital servitization. The first category of antecedents (A1) refers to the technological elements/digital infrastructure that form a backbone of sustainable digital servitization and provide the digital support required to transition towards service-oriented business models. The key technological elements include the Internet of Things (IoT) (Arioli et al., 2023; Chen et al., 2023; Li et al., 2021; X. Li et al., 2021; Paiola et al., 2021; Vaillant & Lafuente, 2024), AI capacities and AI-driven optimization (Kolagar et al., 2024; Nicoletti & Appolloni, 2023; Sjödin et al., 2023; Vaillant & Lafuente, 2024; Walk et al., 2023), advanced Information and Communication Technology (ICT) infrastructure (Kim et al., 2022; X. Li et al., 2021; Song et al., 2021; Wu et al., 2022), blockchain technology to support secure, transparent data transactions and Cyber-Physical Systems (CPS), which integrate physical processes with digital systems (Li et al., 2021), digital twin integration, which enables real-time monitoring and simulation of products (González Chávez, Unamuno, et al., 2023), technology-enabled autonomous solutions (Sjödin et al., 2023), and use of Virtual Reality (VR) (Bu et al., 2021).

The second category of antecedents (A2) consists of organizational and strategic elements that collectively contribute to successfully implementing digitally enabled sustainable servitization initiatives by providing internal support. This category is divided into skills and capabilities, collaborative networks, and strategic elements. According to critically evaluated literature, skills and capabilities refer to digital skills and competence development (Xie et al., 2023), dynamic capabilities (Bag et al., 2024; Sjödin et al., 2023), absorption, and transformative capacities (Lee et al., 2024), as well as analytics and business intelligence capabilities (Bag et al., 2024). Collaborative communication emphasizes building strong partnerships and communication with stakeholders in the digital ecosystem (Chen et al., 2023; X. Li et al., 2021; Paiola et al., 2021). Measures in this sector include risk mitigation strategies (González Chávez, Unamuno, et al., 2023), sustainability objectives (Mihardjo et al., 2020; Schiavone et al., 2022; Vaillant & Lafuente, 2024), the dynamic pricing strategies (Kumar Jena & Singhal, 2023), and circular strategies (Kim et al., 2022; Menon et al., 2024).

The third category of antecedents (A3), identified in the current literature, consists of the customer-centric elements that ensure that the digital servitization process is driven by a deep understanding of the customer needs and their involvement in the process. Key customer-related elements comprise digital customization for sustainability (Chang et al., 2024), customer feedback loops and co-creation (Bu et al., 2021; Zhu & Hu, 2021) and consumer awareness and expectations (Kabadurmus et al., 2023; Wang, 2024). The last category of the antecedents (A4) covers the market and environmental elements, which contain the market disruption, waste reduction imperative (Kabadurmus et al., 2023), and other influential external factors (González Chávez, Despeisse, et al., 2023).

In conclusion, the antecedents identified, such as technological, organizational, strategic, customer-centric, and market and environment elements, are important in helping the companies move from a product-dominant to a sustainable digital servitization business model. These elements provide companies with the tools, human resources, and strategic directions essential to survive and overcome the challenges of the sustainably servitized digital business models. By managing these antecedents, organizations can create a foundation for successful and enduring digital servitization that caters to the dynamic needs of both business and society. However, it must also be noted that the antecedents identified herein were deduced from the 52 articles included in this review only; other factors may also influence the sustainable digital servitization process. For example, such factors as specific industry segments, the presence or absence of regulative measures that govern specific industries or provincial peculiarities, or factors at the company level.

Furthermore, the interconnections between these antecedents and the process of digital servitization can vary significantly across organizations. Each company's unique background, resources, and strategic priorities can shape its sustainable digital servitization journey. For example, a large firm with advanced digital resources may find it easier to implement IoT-based predictive maintenance (Paiola et al., 2021), while smaller firms may find it difficult due to the lack of advanced technological resources and may focus on incremental enhancements by adopting more straightforward digital services to enhance sustainable practices.

3.2 The sustainable digital servitization process (B)

Sustainable digital servitization has been categorized into complex processes that transform product-focused business models into service-oriented models enhanced by digital technologies. Core processes in sustainable digital servitization recognized in the existing literature include business model innovation and value creation, technology integration and digital transformation, service design and customer-centric innovation, digital ecosystem collaboration and supply chain transformation, and sustainability and circular economy integration. Each process supports companies through their transformation phase towards service-based value creation and allows them to deliver customized, sustainable, and digitally enabled offerings.

The first category in the process (B1) consists of business model innovation, which is central to sustainable digital servitization. Focusing on sustainability allows companies to shift from traditional product-based to service-based value creation driven by integrating digital technologies. Key elements in this category of the process are outcome orientation (González Chávez, Despeisse, et al., 2023; Kolagar et al., 2024), which leads to developing services enabled by data analytics and digital monitoring, circular business model design (Bressanelli et al., 2024; Kim et al., 2022; Sjödin et al., 2023), as it involves redesigning the value chain and operations to support sustainable service-based offerings rather than one-time product sales, pay-per-use business models (Bressanelli et al., 2024; Menon et al., 2024) through which companies position digital monitoring technologies to track usage and optimize service delivery, integrated digital configuration and IoT-driven business models (Kohtamäki et al., 2022; Kumar Jena & Singhal, 2023; X. Li et al., 2021; Rakic et al., 2023) which enable dynamic service adjustments, enhance operational efficiency, and allow companies to deliver more personalized and predictive services, human-centered and resilient business models (Nicoletti & Appolloni, 2023), and dynamic and sustainable pricing business models (Kumar Jena & Singhal, 2023).

The second category in the sustainable digital servitization process (B2) refers to technology integration and digital transformation, which is necessary for successfully implementing digital servitization, as data-driven decision-making enables companies to enhance their service offerings through continuous feedback loops and real-time adjustments. This comprises data-centric service engineering and performance optimization (Arioli et al., 2023; Kabadurmus et al., 2023; Opazo-Basáez et al., 2018) to deliver efficient and high-quality services by monitoring performance metrics and identifying the areas for improvement, integrated digital lifecycle monitoring, and management (González Chávez, Unamuno, et al., 2023; Kruschke et al., 2023; Liu et al., 2020; Wu et al., 2022) which allows for tracking products and providing continuous service over the product's entire life-span, iterative design framework (Arioli et al., 2023; Bu et al., 2021) which allows repeated testing and refining service components, integration of virtual reality (VR) for enhanced user experience (Bu et al., 2021), and deployment of digital platforms (Vaillant & Lafuente, 2024).

The third category (B3) in the sustainable digitally enabled servitization process is service design and customer-centric innovation, which create tailored experiences by prioritizing customer needs and preferences. It includes Customer-Centric Design and Smart Service Development (Bu et al., 2021; Chang et al., 2024; De La Calle et al., 2021;

González Chávez et al., 2024; Münch et al., 2022; Pirola et al., 2020), Digital Interaction and Service Innovation through Technology (GÜR, 2023; Münch et al., 2022), and Collaborative and Iterative Design Frameworks (Arioli et al., 2023; Bressanelli et al., 2024; Ries et al., 2023; Wu et al., 2022).

The fourth category (B4) is digital ecosystem collaboration and supply chain transformation, which are vital in sustainable digital servitization by enabling companies to leverage partnerships and integrate more efficiently. It consists of the collaborative digital transformation and stakeholder engagement (Behl et al., 2024; Jankovic-Zugic et al., 2023; Li et al., 2021; Upadhayay et al., 2024), value co-creation/ecosystem composition (Kolagar, 2024; Kolagar et al., 2024; Zheng et al., 2019), collaborative innovation in the logistics (Pan et al., 2019), collaborative and integrated systems for the circularity (Alcayaga & Hansen, 2024; Kim et al., 2023), and the sustainable supply chain coordination (De La Calle et al., 2021; Kumar Jena & Singhal, 2023; X. Li et al., 2021).

The last category in the process (B5) focuses on sustainability and circular economy integration, which are integral to sustainable digital servitization and aim to reduce environmental footprint while maintaining the service value. This category contains elements such as collaborative circularity and lifecycle management (Alcayaga & Hansen, 2024; Kim et al., 2023; Kohtamäki et al., 2022; Pirola et al., 2020; Zheng et al., 2019), circular design, and reversible strategies (X. Li et al., 2021; Ries et al., 2023; Zhu & Hu, 2021), sustainable product-service system development (GÜR, 2023; Li et al., 2021; Nicoletti & Appolloni, 2023; Wang, 2024; Zhu & Hu, 2021), and exaptation of manufacturing processes (Schiavone et al., 2022).

The selected literature provides valuable insights into these processes, highlighting best practices and potential challenges in digital servitization and acknowledging that many other elements, such as organizational change management and employee characteristics, are vital processes. However, this study covers the broad categories of the digital servitization process discussed in the sample literature.

3.3 Outcomes (C)

Following a phase of a sustainable digital servitization process, several outcomes have been identified in the selected literature. Digital servitization yields outcomes that enhance business performance and contribute to broader sustainability goals. These outcomes have been divided into four categories: Operational Efficiency and Financial Performance, Enhanced Collaboration and Ecosystem Synergies, which refer to economic sustainability, Social Sustainability and Human Development, and Environmental Sustainability and Circular Economy Outcomes.

The first outcomes category (C1) is Operational Efficiency and Financial Performance. It is divided into three themes: Cost Reduction and Resource Optimization, Profitability and Revenue Growth, and Enhanced Decision-Making and Process Automation. Cost reduction and resource optimization are important aspects of enhancing financial performance. Efficiently managing resources can significantly cut down on expenses (Bressanelli et al., 2024; Kim et al., 2022; Kolagar et al., 2024; Kumar & Sharma, 2023; X. Li et al., 2021; Sjödin et al., 2023). This outcome not only includes the allocation of resources more efficiently to minimize production requirements and associated costs (Halstenberg et al., 2021) but also attains cost savings and better resource use while generating new income through the service-based offerings (González Chávez, Despeisse, et al., 2023; GÜR, 2023).

Moreover, strategies such as smart circular product-service systems capabilities (SCPC) can positively influence financial performance by reducing costs like waste management and raw material sourcing (Bag et al., 2024). Reducing costs throughout the product lifecycle (Zhu & Hu, 2021) also contributes to this goal. Additionally, predictive maintenance, which uses advanced analytics to anticipate equipment failures and minimize unexpected stoppages, is crucial (X. Li et al., 2021; Mauersberger et al., 2023; Opazo-Basáez et al., 2018). It reduces downtime and boosts benefits through better resource use and additional income from the service offerings (Jankovic-Zugic et al., 2023). Overall, these strategies work to optimize resources and reduce costs, thereby improving financial outcomes.

It is crucial to increase the level of profitability and generate the revenue growth for the business development. Such strategies include increasing an operation's efficiency (Menon et al., 2024) and incorporating digital servitization for market resilience (Xie et al., 2023), which can significantly improve profit margins. Gaining a competitive edge through digital services (Kabadurmus et al., 2023) and linking green innovation to profitability (Lee et al., 2024) further strengthen a market position. For revenue expansion, customized offerings that meet diverse customer needs can unlock new markets and profits (Chang et al., 2024). The AI-driven condition-based maintenance (Sjödin et al., 2023) constructs a new income stream while cutting costs. Improving the supply chain efficiency with digital servitization reduces expenses, enhances accuracy, and opens new revenue avenues (Li et al., 2021). Finally, optimizing the inventory and employing dynamic pricing maximizes profits (Kabadurmus et al., 2023).

Companies can make more informed and effective decisions by leveraging data-driven insights (Kabadurmus et al., 2023; Kruschke et al., 2023; Liu et al., 2020). It allows businesses to base their strategies on solid data, leading to better outcomes and a competitive edge. Moreover, the automation of routine processes (González Chávez et al., 2024; Halstenberg et al., 2021; Opazo-Basáez et al., 2018) not only increases efficiency but also frees up valuable time and resources. This enables employees to focus on more strategic tasks, ultimately driving the business's growth and success.

The second category, labelled Enhanced Collaboration and Ecosystem Synergies (C2), discusses the Integrated Value Chain Collaboration (Alcayaga & Hansen, 2024; Chen et al., 2023; Kim et al., 2023), the Cross-Industry Innovation and Co-Creation (Kolagar, 2024; Kolagar et al., 2024), An Increased Network Agility and Responsiveness (Jankovic-Zugic et al., 2023; Paiola et al., 2021; Pan et al., 2019) and the Mutual Value Creation through Stakeholder Engagement (Behl et al., 2024; Li et al., 2021; Upadhayay et al., 2024).

The third outcomes category, Social Sustainability and Human Development (C3) includes Social Inclusion and Accessibility, Skill Development and Employment, Employees' and Consumers' Well-being, Stakeholder Collaboration and Engagement, Societal Resilience and Well-being, and the Value Creation and Satisfaction themes.

(Bressanelli et al., 2024;Kim et al., 2022; Rakic et al., 2023) highlight the importance of increasing accessibility to the services, ensuring that a broader range of people can benefit from what is on offer. This ties in closely with a need for improved equality of access to technology and services, as also emphasized in the same studies. Furthermore, enabling social participation and co-creation in social inclusion (Chang et al., 2024; De La Calle et al., 2021; Pirola et al., 2020) adds another layer to this approach. The division makes these services more inclusive and guarantees that the services created address the needs of a diverse community in the process (Chang et al., 2024; De La Calle et al., 2021; Pirola et al., 2020).

In this digital age, focusing on skill development and employment opportunities is more important than ever (Chang et al., 2024; González Chávez et al., 2024; Kumar & Sharma, 2023; Xie et al., 2023). By equipping individuals with the necessary digital skills, businesses can open up new job opportunities, helping people thrive in the modern workforce. Furthermore, involving the stakeholders in skill-enhancement initiatives (Kolagar, 2024) ensures that these efforts align with the industry's and the community's needs. Moreover, when employees feel empowered and work in a safe environment, it leads to higher job satisfaction and productivity (Bu et al., 2021; González Chávez, Unamuno et al., 2023; Opazo-Basáez et al., 2018). Similarly, enhancing health and safety standards is crucial for protecting the well-being of workers. On the consumer front, ensuring food safety and hygiene is vital for maintaining public health (Kabadurmus et al., 2023).

Engaging the stakeholders throughout the product lifecycle promotes inclusivity and enhances accountability (Kolagar et al., 2024;Li et al., 2021). This collaboration builds trust, creates jobs, and improves safety (González Chávez, Despeisse, et al., 2023; Jankovic-Zugic et al., 2023). Furthermore, enhancing stakeholder collaboration and consumer engagement in sustainable practices (Halstenberg et al., 2021) leads to better outcomes. It is also important to prioritize stakeholder inclusivity, user satisfaction, and health and safety considerations to balance social impacts (Liu et al., 2020; Wu et al., 2022). Lastly, ensuring inclusivity in decision-making for Smart Product-Service Systems (Smart PSS) is key to creating smart systems that benefit everyone (Zhu & Hu, 2021).

Building societal resilience is essential for withstanding and recovering from crises (Bressanelli et al., 2024; Li et al., 2021; Upadhayay et al., 2024). Additionally, efforts to reduce accident rates and improve traffic management contribute significantly to societal well-being (Wu et al., 2022). These initiatives help create a safer and more efficient environment for everyone. Creating sustainable value propositions increases employee satisfaction and better social responsibility outcomes (Xie et al., 2023). Moreover, improving competitive positioning and customer satisfaction helps businesses thrive while keeping customers happy (Vaillant & Lafuente, 2024). Lastly, enhancing collaboration between manufacturers and distributors improves job satisfaction and reduces errors, leading to a more efficient and content workforce (Arioli et al., 2023).

The last outcomes category, Environmental Sustainability and Circular Economy Outcomes (C4) includes Energy Optimization and Carbon Reduction, Resource Efficiency and Waste Reduction, Lifecycle Management and Circular Economy, and Technology-Enabled Environmental Improvements. On the energy front, businesses are focused on shrinking their carbon footprint by making the processes more efficient (Kruschke et al., 2023; Opazo-Basáez et al., 2018; Wang, 2024). Optimization of energy use across operations is also taking place as a result of digital servitization (Chang et al., 2024; X. Li et al., 2021; Opazo-Basáez et al., 2018; Wang, 2024). Furthermore, supply chain fine-tuning is leading to reduced carbon emissions (Jankovic-Zugic et al., 2023; Kruschke et al., 2023; Wang, 2024).

Digital servitization helps in reducing waste and optimizing material usage across various sectors (Chang et al., 2024; GÜR, 2023; Kim et al., 2022; X. Li et al., 2021; Sjödin et al., 2023; Zheng et al., 2019; Zheng et al., 2020). Improvements in recycling and waste management are also evident. Digital twin technology is pivotal in enhancing resource efficiency (X. Li et al., 2021; Mauersberger et al., 2023; Opazo-Basáez et al., 2018). Kabadurmus et al. (2023) specifically address the reduction of food waste and the enhancement of overall resource efficiency, while Zhu and Hu (2021) emphasize the general initiative to reduce waste (Zhu & Hu, 2021).

Lifecycle Management and Circular Economy (Alcayaga & Hansen, 2024; Bressanelli et al., 2024; Chang et al., 2024; Kim et al., 2022; Lee et al., 2024; Liu et al., 2020; Mauersberger et al., 2023; Vaillant & Lafuente, 2024; Wu et al., 2022; Xie et al., 2023) and Technology-Enabled Environmental Improvement (Arioli et al., 2023; Chen et al., 2023; Li et al., 2021; Sjödin et al., 2023)are some other outcomes discussed in several studies under the last category of Environmental Sustainability and Circular Economy Outcomes. The outcomes discussed here are identified from the selected literature and represent the core findings within the scope of this study. Other outcomes may emerge from different contexts, industries, or specific implementations of the sustainable digital servitization process.

In summary, this framework aligns with Pettigrew's (1997) emphasis on processual analysis, which links digital servitization's antecedents, processes, and outcomes. It explains what outcomes are achieved, why, and how they are connected to the antecedent elements and processes. As a result, three distinct research areas have been identified. The first research area examines the antecedent factors that influence the processes and implementation of digital servitization. The second area studies the processes involved in digital servitization, exploring the influence of various factors (antecedents) and their impact on the transformation. Finally, the third area investigates the diverse outcomes that result from the digital servitization process. These three research areas in the literature and interrelationships of factors are illustrated in the linkage-exploration review matrix (see Figure 3), while the summary of all studies included in the sample is provided in Table A1 in the appendix 1. The table shows the study code (two-digit key), author, type of paper (quantitative, qualitative, conceptual, SLR, or others), sample size, sample characteristics, linkages between studies, core findings, and digital servitization and sustainability focus. A detailed exploration of these findings will follow in the next chapter.

Figure 3. Linkage-Exploration Review Matrix

	B*	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4
A1	03, 07, 10, 22, 32, 41, 42	07, 20, 30, 36, 41	02, 06, 14, 18, 27, 44	02, 06	08	08, 36, 48, 50					
A2	10, 28, 32, 49	07,13, 19, 23, 36, 41	14, 44		19,23	24, 36, 40, 48					
A3			06, 18	06, 09		46, 52					
A4	10, 12	13	18								
B1				05, 11	01,11,19,20,23, 33	01, 36	01, 05, 07, 11, 13, 19, 20, 23, 30, 33, 36, 38, 41				
B2				02, 06, 47		25, 31	02, 06, 14, 18, 21, 25, 27, 31, 44, 47				
B3		05, 11	02,06, 47		11	15, 35, 39	02, 05, 06, 09, 11, 12, 15, 29, 35, 39, 47				
B4		01, 11, 19, 20, 23, 33		11		01, 08, 50	01, 04, 08, 11, 17, 19, 20, 23, 33, 43, 48, 50				
B5		01, 36	25, 31	15, 35, 39	01, 08, 48, 50		01, 08, 15, 16, 24, 25, 26, 31, 35, 36, 39, 40, 46, 48, 50, 51, 52				
B6								03, 05, 07, 08, 09, 13, 15, 16, 17, 18, 20, 21, 22, 24, 25, 27, 28, 31, 36, 41, 49, 52	01, 04, 08, 17, 19, 20, 33, 43, 50	02, 04, 05, 06, 07, 08, 09, 11, 12, 13, 14, 16, 17, 18, 19, 20, 22, 25, 31, 35, 36, 38, 39, 40, 43, 44, 47, 49, 52	01, 02, 03, 05, 06, 07, 08, 09, 10, 12, 13, 15, 16, 17, 18, 19, 20, 21, 24, 25, 27, 31, 36, 41, 44, 46, 47, 48, 49, 50, 51, 52

A1: Technological Elements/ Digital Infrastructure
A2: Organizational and Strategic Elements
A3: Customer-Centric Elements
A4: Market and Environmental Elements
B*: Sustainable Digital Servitization process as a whole

B1: Business Model Innovation and Value Creation
B2: Technology Integration and Digital Transformation
B3: Service Design and Customer-Centric Innovation
B4: Digital Ecosystem Collaboration & Supply chain Transformation
B5: Sustainability and Circular Economy Integration
B6: Process Conclusion

C1: Operational Efficiency and Financial Performance
C2: Enhanced Collaboration & Ecosystem Synergies
C3: Social Sustainbility and Human Development
C4: Environmental Sustainability and Circular Economy Outcomes

4 Review of the Literature

This chapter explores and emphasizes sustainable digital servitization's integrative framework, providing a deeper analysis of linkages among antecedents, processes, and outcomes. This chapter systematically analyses prior research and emphasizes theoretical advancements, methodological approaches, and findings on how digital servitization enables sustainability. Key areas of exploration include the influence of enabling factors, the role of innovative processes, and the resulting impacts on environmental, economic, and social dimensions. Not every study in the sample is mentioned here due to space consideration; only significant finding and their recurring insights are emphasized to give a better idea of the field. The review of literature is an essential foundation for understanding the complexities of sustainable digital servitization. This chapter provides an overview of theoretical contributions and potential methodological and empirical contributions in the prior literature on integrating digital technologies with servitization for sustainability.

4.1 Studies on the linkage between antecedent factors and sustainable digital servitization process

This section discusses the antecedents and their influences on the processes of sustainable digital servitization.

4.1.1 Technological Elements/Digital Infrastructure (A1)

Sustainable digital servitization depends heavily on digital infrastructure. One of the most crucial antecedents of digitally enabled servitization fostering sustainability is Technological elements. Hence, a body of literature has recognized various technological elements that enable the transformation process, increase operational efficiency, enhance customer experience, and drive sustainability in organizations. This systematic literature review has discussed technologies, such as IoT, AI, and advanced ICT infrastructure, influencing sustainable digitally enabled servitization. For instance, Paiola et al. (2021) highlight the critical role of IoT in converting traditional manufacturing models into service-oriented business models. Research states that the Internet of Things (IoT) is a key driver in encouraging businesses to rethink their strategies. IoT enables remote monitoring and control of customers’ equipment performance, which reduces downtime and energy consumption and ensures optimal equipment functions, thus contributing to the environmental sustainability goals. Furthermore, they describe IoT facilitates collaboration and integration within business ecosystems by enabling companies to build strong relationships with their stakeholders and enhance value through co-creation (Paiola et al., 2021).

Considering the importance of the Internet of Things (IoT), Li et al. (2021) state that it enhances traceability and transparency across the supply chain, resulting in optimized use of resources and reduced waste. He has proposed a platform to strengthen the sustainability of Prefabricated Housing Construction (PHC) by integrating different technologies like Building Information Modelling (BIM), Cyber-Physical Systems (CPS), the Internet of Things (IoT), and blockchain. In the same way, Bag et al. (2024) pinpoint the Internet of Things (IoT) as the enabler of Smart Circular Product-Service Systems (SCPC) within Industry 4.0. They elaborate that IoT allows the connection of such devices that track product performance, usage, and life cycle stages, facilitating real-time data collection and monitoring. It broadens the development of Product Lifetime Databases that record the entire lifecycle of products from manufacturing to disposal.

IoT also improves the actuating capability of systems, enabling self-diagnosis, automation, and optimization of recycling and resource utilization processes. IoT promotes collaboration across supply chains as it allows the sharing of information among stakeholders. Moreover, more efficient business intelligence tools can mine IoT-generated data for designing products for recyclability and reuse. Finally, Bag et al. (2024) describe that IoT directly supports sustainability goals by extending product lifecycle span, enabling closed-loop material flows, and allowing reuse and remanufacturing, thus proving its role as a backbone for SCPC and circular supply chains in Industry 4.0 era (Bag et al., 2024).

Besides the foundational role of IoT, this literature review also emphasizes the significant role of AI capabilities. Artificial intelligence (AI) is one of the essential enablers of sustainable digital servitization that allows industrial companies to transform into more resource-efficient and greener businesses. Referring to Kolagar et al. (2024), it has been stated that AI optimization is the key enabler of smart solution thinking that wastes resources and improves decision-making towards creating customer sustainability. They further stress that AI offers repositioned and outcomes-as-a-service models focused on eliminating wastes and emissions together with ecosystem management and value creation (Kolagar et al., 2024). In the same manner, Sjödin et al. (2023) stress AI's perceptive, predictive and prescriptive capabilities as the enablers of CBMI that incorporate the circularity concepts such as reuse, recycle and dematerialization (Sjödin et al., 2023). While Kolagar et al. (2024) are concerned with the configurational strategies enabled by AI, Sjödin et al. (2023) investigate the automation and augmentation of business models by AI. These investigations confirm that AI simultaneously constitutes the technological requirement for operational excellence and a catalyst to encourage further strategic advancements, rendering it vital for the realisation of sustainable digital servitization.

Another important technological element is the Advanced ICT infrastructure. This makes sustainable digital servitization possible and provides the technological environment that supports innovation and sustainability. Bu et al. (2021) discuss an enhancement of using virtual reality (VR) in smart product-service systems (PSS), where the data generated by users and the system contribute to value-added services as well as enhance product lifecycle sustainability. Likewise, Kim et al. (2022) highlight that it is crucial to cultivate digital capabilities such as IoT and data-driven systems in enhancing CEBMs in the electrical and electronic equipment sector, exhibiting considerable improvements in resource efficiency in waste generation in Singapore and South Korea and building upon this perspective Song et al. (2021) present a Rough-BWM-CRITIC-TOPSIS method for enhancing the design evaluation of smart PSS, demonstrating how real-time data and

intelligent systems enhance the decision-making and lifecycle.
Furthermore, Upadhayayet al. (2024) establish that ICT, through technologies like AI, IoT, and cloud computing, is integral to digital servitization, driving firm-level innovation and enhancing synergies with green servitization in achieving circular economy goals. These studies illustrate ICT's transformative impact in enabling data-driven, sustainable, innovative servitization frameworks across diverse sectors.

Apart from IoT, AI, and advanced ICT infrastructure, various other technological elements have been highlighted in the literature as antecedents of sustainable digital servitization, contributing to enhanced efficiency, sustainability, and innovation. These technologies include blockchain, Cyber-Physical Systems (CPS), product lifetime database creation capabilities, digital twins, data-driven decision support systems, technology-enabled autonomous solutions, and Virtual Reality (VR). Each of these plays a distinct role in driving the digital transformation of industries, as discussed below.

Blockchain technology is identified as a crucial enabler for the sustainability of supply chains. For instance, research highlights the role of blockchain and ensures transparency and traceability within the prefabricated housing construction sector (Li et al. (2021). With the help of secure maintenance, a decentralized database, real-time examination, collaborative decision-making and blockchain facilities among the stakeholders, it can ultimately reduce inefficiencies and enhance resource optimization. Also, CPS complements the blockchain by integrating the digital and physical components to connect unified systems that can enhance automation and sustainability. Another research highlights how CPS enables real-time data capture and improves operational efficiency in complex supply chains such as prefabricated housing (Li et al., 2021).

Another technological advancement is highlighted, which helps create product lifetime databases supporting the circular economy Bag et al. (2024). These databases help track and manage products thoroughly in the lifecycle and facilitate remanufacturing, redistribution, and waste reduction. These capabilities are valuable for increasing product life and helping achieve environmental sustainability in dynamic business environments. Another concept that complements it is digital twins, which are considered a transformative tool in manufacturing Mauersberger et al. (2023). The digital twin replicates and monitors real-world systems in real-time, enabling predictive maintenance, improving design processes, and optimising performance, contributing to sustainability and operational efficiency.

Data-driven decision support systems are vital for smart product-service systems (PSS). For example, Kabadurmus et al. (2023) propose a model leveraging real-time data from smart packaging to optimize grocery supply chains. This system adjusts the pricing and inventory management, reduces food waste and improves profitability, mainly during disruptions like pandemics. In parallel, the technology-enabled autonomous solutions represent advanced stages of digital servitization. These innovations include self-driving drones and vehicles, which use AI and IoT to provide smart, self-optimizing systems (Sjödin et al., 2023). These autonomous solutions improve the customer experience and enhance resource efficiency and productivity.

Lastly, virtual reality (VR) is considered to have the potential to improve user-centric design in smart PSS. Bu et al. (2021) exemplify how VR integrates user-generated and system-generated data to improve product design, user experience, and sustainability in product lifecycle management. This technology facilitates real-time data processing and ergonomic assessments, creating value-added services and supporting sustainable strategies. This systematic literature review shows the growing focus on these advanced technological elements as the enablers of sustainable digital servitization. While each technology addresses the specific aspects of sustainability and efficiency, their combined integration within the smart systems offers significant potential for advancing circular economy practices and achieving holistic digital transformation.

Technologies like IoT, AI capacities, blockchain, CPS, digital twin integration, and VR enable the various process elements, improving decision-making, user experience, and stakeholder collaboration. These linkages determine the complementary nature of the advanced technologies in shaping the sustainable digital servitization frameworks.

The Internet of Things (IoT) and artificial intelligence (AI) primarily provide data-driven service engineering and performance optimization by delivering the necessary predictive analytics and real-time monitoring. With its foundation for ongoing service improvements, IoT makes obtaining and reviewing the working data easier and possible. For example, according to the study's findings, the IoT sensors allow the smart PSS system performance to be evaluated adequately and address disruptions correctly (Bag et al., 2024). Similarly, the AI provides forecasting, resource allocation and operating efficiency, as Kolagar et al. (2024) stated. These technologies are more effective than conventional tools that use static data to present valuable achievements since they only simultaneously connect the data generation process and the option.

Blockchain and CPS are the digital technologies necessary for digital lifecycle management integration. These technologies also ensure that the data exchange is protected and has real-time tracking. According to Li et al. (2021), CPS consists of the physical and digital aspects, providing detailed information on the lifecycle stages to enable sustainability practices. Blockchain integrates with this by providing data integrity and traceability, which are needed in decentralized sectors like the prefabricated house construction industry. Combined, they are on the order of conventional methods and much more effective in developing integrated platforms for lifecycle monitoring. Decision-making is also advanced by the DSS (Decision Support Systems) system. IoT and AI assist decision-making by incorporating the data into the working systems. For example, Kabadurmus et al. (2023) demonstrate how such systems can enhance the inventory and pricing tactics so that the waste in the supply chain networks can be reduced and productivity can be increased during disruptions. IoT enables data gathering while AI’s predictive equations guarantee dynamic changes, which, in total, improve and promote decision-making.

To enhance the user experience, VR emerges as a transformative technology. It supports immersive and interactive platforms combining user input with system-generated data to improve product design and lifecycle management. Bu et al. (2021) emphasize how VR-assisted systems deliver personalized solutions that significantly boost user satisfaction—unlike the traditional design methods, which lack iterative feedback capabilities.

Furthermore, blockchain and IoT support value co-creation and effective ecosystem orchestration. According to Kolagar et al. (2024), these technologies foster stakeholder trust and collaboration, aligning the partnerships with sustainability goals. CPS supports this by enabling interactive innovation within a collaborative digital ecosystem, as seen in the construction industries (Li et al., 2021).

Conclusively, the digital twin technology combined with IoT revolutionizes sustainable supply chain coordination. Digital twins simulate logistical scenarios, offering predictive insights that enhance resource allocation and operational planning. As Mauersberger et al. (2023) assert, these innovations provide real-time visibility and promote sustainability within supply chains, representing a significant leap from traditional models.

In conclusion, the advanced technologies collectively enable sustainable digital servitization by addressing the distinct process elements with targeted solutions. While each technology has its unique role, its integration often yields compounded benefits, illustrating an interconnected nature of innovation and optimization. Future studies should research deeper into coordinating these technologies to maximize their collective impact on sustainability and industrial transformation.

4.1.2 Organizational and Strategic Elements (A2)

The analysis of the selected literature sample revealed organizational and strategic elements (A2) as the antecedents for sustainable digital servitization. Based on these elements, they underline key success factors in implementing digital change by embracing sustainability. They are broadly categorized into three key areas; digital skills and competencies that concern the construction of digital and transformative capabilities, strategic aspects that link the organizational strategy to sustainable actions and networks for collaboration that address partnership and innovation systems.

Kolagar (2024) and González Chávez, Despeisse, et al. (2023) emphasize that digital skills, competencies, and upskilling are the critical enablers of sustainable digital servitization, ensuring a smoother transition. Training and innovation programs are essential for equipping employees with technical competencies, like data analysis, cybersecurity, and cloud computing, while fostering digital literacy and familiarity with the provided data-driven tools. Such initiatives ensure that the employees are prepared for emerging technologies, including automation and artificial intelligence, enabling seamless adaptation to digital processes. On the contrary, Kolagar (2024) emphasize the significance of managerial skills, like effective communication and relational abilities, which are critical for building strong customer relationships and nurturing collaboration across ecosystems. Moreover, González Chávez, Despeisse, et al. (2023) highlight the role of upskilling in overcoming resistance to change, as the employees equipped with the necessary skills are more likely to embrace the innovative processes. By investing in these capabilities, organizations facilitate the transition to digital servitization, enhance technical proficiency, support the integration of digital tools, and drive sustainable value creation. These skills can then be leveraged as core competencies that support organizations in addressing the complicated challenges of sustainable digital servitization to create sustainable business systems that have long-term sustainability objectives (González Chávez, Despeisse, et al., 2023; Kolagar, 2024).

Besides, digital and managerial skills, dynamic capabilities, absorptive and transformative capacities, and analytics and business intelligence capabilities are cited as the specific drivers of sustainable digital servitization in different studies, while their causal relations are discussed. Sjödin et al. (2023) highlight the importance of dynamic capabilities in helping firms adapt to the rapidly evolving digital servitization and sustainability landscape. They elaborate that these capabilities allow organizations to sense, seize, and reconfigure internal and external resources to respond to market demands and technological changes. However, the most critical dynamic capabilities are at the heart of the circular business model innovation (CBMI) because they harness advanced technology, such as AI, to optimize the various resources to create sustainable solutions (Sjödin et al., 2023).

Building on this, Lee et al. (2024) focus on the absorptive and the transformative ones as strategic and dynamic capabilities vital for successful sustainable digital servitization. Whereas absorptive capacities enable the organization to absorb and transform external knowledge, transformative capacities facilitate using this knowledge for organizational change for sustainable innovation and process improvements. These capacities are most relevant in uncertain and technological environments because they enable the firms to adjust and stay relevant in cases of shifting requirements. Combined with the above, they contribute to developing principles of green innovation and helping firms transform into sustainable organizations (Lee et al., 2024).

In supporting the above ideas, Bag et al. (2024) also emphasize the critical role of analytics and business intelligence capabilities in supporting dynamic capabilities within circular supply chains. These capabilities enable the firms to collect, analyse, and interpret data, providing valuable insights for optimizing operations and fostering innovation. Therefore, Analytics and AI capacities constitute an essential platform for building smart product-service systems applying digital enablers to improve resource management and environmental performance (Bag et al., 2024). These studies present a composite picture of the nature of organizational capabilities for sustainable digital servitization. Absorptive and transformative analytics and business intelligence capabilities enhance the firms’ dynamic capabilities as they jointly manage the multiple facets of digital transformation and advance their innovation and sustainability goals.

Collaborative networks represent another key subcategory of antecedents in the organizational and strategic enablers for sustainable digital servitization. As mentioned in the literature by different authors, these networks are focused on partnerships and ecosystem orientation as the key enablers of innovation and sustainability. According to Chen et al. (2023), digital ecosystem collaboration is crucial for achieving sustainability in digital servitization. They explain that integrating private and public architects within one digital environment benefits resource exchange, innovation, and value co-creation. They also clarify that by joining those ecosystems, firms have better access to new digital infrastructures, including IoT or cloud, within the servitization process, mainly enhancing organizational environmental outcomes as organizations share their sustainable practice to use resources efficiently (Chen et al., 2023).

Expanding on this perspective, X. Li et al. (2021) focus on the role of collaborative networks in developing sustainable smart product-service systems (PSS). They emphasize how these networks facilitate data sharing and co-development among various stakeholders, including manufacturers, service providers, and end-users. These networks support lifecycle optimization through a reversible framework, enabling reuse, remanufacturing, and recycling practices. When integrating cyber-physical resources, collaborative networks enhance system adaptability, drive sustainable innovation, and contribute to advancing circular economy principles (X. Li et al., 2021). Moreover, Paiola et al. (2021) highlight the importance of inter-organizational networking in facilitating a shift from product-centric to service-centric business models. Based on multiple case studies of IoT-driven business models, they demonstrate how can strong partnerships and alliances within these networks promote knowledge exchange and innovation, allowing firms to address complex sustainability challenges and develop integrated solutions that align with environmental and common goals, building sustainable value chains through the shared expertise (Paiola et al., 2021). Together, these studies highlight the multidimensional contributions of collaborative networks to fostering sustainability and innovation in digital servitization.

Strategic elements guide firms to align their operational goals with sustainability and digital servitization goals, addressing the key challenges and fostering innovation. González Chávez, Unamuno, et al. (2023) highlight the critical role of risk mitigation strategies in digital servitization, mainly in the machine tool industry. They recognize that the transition to digital services brings such issues as data privacy, integration issues, and lifecycle issues. The authors present structured mitigation strategies for such complexities, including improving data governance procedures, the involvement of stakeholders, and synchronizing the lifecycle. They help facilitate the implementation of sustainable digital servitization strategies and minimize the likelihood of economic or operating disruptions González Chávez, Unamuno, et al. (2023).

Mihardjo et al. (2020) have argued for the closer alignment of digital transformation initiatives with sustainability goals. They point out that implementing Green Information Systems (GIS) can improve the firm's operational flexibility, customer satisfaction and digital services' dynamism for sustainable business as usual. Similarly, Schiavone et al. (2022) also note that sustainability contributes to achieving environmental and social goals within the servitization in the digital environment to support the operational efficiency of the firms. These objectives inform the development of digital solutions to meet long-term environmental sustainability goals (Mihardjo et al., 2020; Schiavone et al., 2022).

Schiavone et al. (2022) also emphasize that the precise definition of digital servitization is important to use Industry 4.0 technologies in manufacturing systems. This strategy entails reinvading conventional service delivery methods to a digitally supported model. The authors stress that such strategies increase operational performance and let firms fulfil sustainability goals by optimising resource consumption and minimizing losses during the production and service life cycle (Schiavone et al. 2022).

Kim et al. (2022) investigate circular strategies as a fundamental element of digital servitization in the electrical and electronic equipment sector. They appreciate that the application, for instance, recycling, reusing and remanufacturing of products, enhances the efficiency of the resource and minimizes waste. The authors also acknowledge that the enablers of such circular practices include enabling digital management of resource loops and increasing lifecycle (Kim et al., 2022).

According to Kumar Jena and Singhal (2023), dynamic pricing strategies are important in digital servitization, particularly in the digital supply chain context. Through real-time information and analysis, firms can change their pricing strategies and provide the appropriate price changes to the changing market and customer trends. This approach makes the best utilization of resources and raises the customer's competitiveness and satisfaction, making sustainable supply chain management possible (Kumar Jena & Singhal, 2023).

The integration of the organizational and strategic factors (A2) to the key processes (B1–B5) of digital servitization has thus been well discussed in the literature and revealed a transformative nature of the strategic resources, the network of partnerships and sustainability concerns. Different works corroborate how these elements are basic enablers to support business model transformation, technology integration, and ecosystem collaboration.

Dynamic pricing and the goal of sustainability (A2) are associated with Innovations in the business models (B1). For instance, the dynamic pricing approaches include pay-per-use types of models (Kumar Jena & Singhal, 2023) that, consistent with the circular economy model, involve the use of resources with minimum wastage and maximum extension of the product life cycle (Bressanelli et al., 2024; Menon et al., 2024). Similarly, the sustainability goals (Schiavone et al., 2022) define the stability and human-centric business model while keeping the environmental impact on the decrease and viable. Research also explores integrated digital configuration (Kumar Jena & Singhal, 2023; Li et al., 2021; Rakic et al., 2023) as enablers of new value-creation opportunities, exemplifying how these organizational strategies support novel business transformation.

Integrating advanced technologies into servitization processes (B2) requires digital skills and analytical capabilities (A2). For example, data-centric service engineering and lifecycle monitoring (Arioli et al., 2023; Kabadurmus et al., 2023; Opazo-Basáez et al., 2018) for resource optimization and waste management directly supports sustainability (Vaillant & Lafuente, 2024) and circular economy facilitation by optimizing energy usage and minimizing waste during operations .

Organizations' digital skills and competencies play a very central role in building up the resilience and sustainability of the supply chain. Despite this, leveraging the ecosystems requires advanced digital skills to coordinate the ecosystems by deploying data-driven digital services and solutions. As highlighted by Kolagar et al. (2024), these aspects ensure the integrated working of the ecosystem partners concerning the mainstreamed sustainability goals (Kolagar et al., 2024).

Furthermore, integrating the aforementioned digital skills also improves the creation of sustainable practices, including lifecycle monitoring and green logistics in the firm. In another article, Kumar Jena and Singhal (2023) provide an example of how supply chain managers within manufacturing industries utilizing digital competencies can achieve the above objectives of sustainability through technological tools such as blockchain and AI. These technologies help monitor environmental impacts in real-time and ensure the sustainability of supply chain decisions for ecological and economic objectives (Kumar Jena & Singhal, 2023).

The absorptive and transformative capacities (A2) are the dynamic capabilities necessary to underpin the environmental strategy development (B5) within digital servitization. Lee et al. (2024) note that absorptive capacity helps firms acquire and exploit external knowledge, such as green technologies, while transformative capacity ensures this knowledge is recycled to transform operations for sustainability. When these capabilities are integrated with environmental strategies, firms can improve their capacity to evaluate, analyse, and manage environmental effects (Lee et al., 2024).

As supported by Schiavone et al. (2022), the digital servitization strategies (A2) help to exalt the current manufacturing processes (B5) and align firms with systems that help achieve circular economy goals. For instance, via certain servitization elements like digital interfaces and IoT for monitoring, manufacturers can enhance their resource efficiency, operation robustness flexibility and durability of the product service (Schiavone et al., 2022).

The collaborative networks (A2) generate the context for the emergence of circular design and reversible strategies (B5) since these always foster multidisciplinary and multi-organizational approaches. Li et al. (2021) state that collaborative networks engage the stakeholders in creating joint sustainable solutions with the help of shared digital resources. These networks enable the development of goods and services that are by design circular and encompass design elements for circularity, including modularity, recyclability, and adaptability. It strategically aligns the organizational elements (A2) with the processes (B1–B5), which ensures circular strategies, innovation, lifecycle optimization, and collaboration to reduce environmental impacts, resilience, and long-term resource-locked value from sustainable digital servitization.

4.1.3 Customer-centric Elements (A3)

A third category of the antecedent of sustainable digital servitization relates to customer factors. These elements can be combined with the market and environment elements (A4). However, they are grouped differently to ensure that the most important ones are highlighted well. Some studies have focused on the extent to which various customer-oriented factors are fundamental to achieving the sustainable digital servitization process. According to the selected literature, these elements are digital customization for sustainability, customer feedback, co-creation, and consumer awareness and expectations.

Based on the conception of Chang et al. (2024), digital customization is confirmed to be one of the key sources of sustainability in smart product-service systems (PSS). They argue that through customization brought about by IoT and big data platforms, companies can respond to customer demand, eliminating waste while increasing resource utilization. Thus, solving specific customers' needs enhances their satisfaction and contributes to sustainable development by making production processes more effective and decreasing the negative environmental impact (Chang et al., 2024).

On the other hand, Bu et al. (2021) reveal that the feedback loop with the customers and their involvement in the process will assist in creating user-oriented smart PSS. In terms of healthcare solutions, they explain how customers' feedback can help companies adapt the design and functionality of their products in near real-time. This continuous process improves customer satisfaction and delivers sustainable value since the products developed meet the customers' needs (Bu et al., 2021).

Zhu and Hu (2021) give a view similar to the one presented, underlining that feedback loops and co-creation are needed to foster sustainable smart PSS. According to them, bringing the customers into the design and delivery processes allows organizations to co-create value with stakeholders, which leads to constant improvement of services and sustainability since offerings are in tune with customers’ needs. They underscore the significance of leveraging smart technologies to capture real-time feedback, enabling iterative service enhancements that drive customer engagement and satisfaction (Zhu & Hu, 2021).

Several studies emphasize the essentiality of consumers’ awareness and their expectations regarding the growth of sustainable digital servitization. Kabadurmus et al. (2023) note that the growing levels of consumer expectations for business transparency and sustainability have posed the need for companies to employ smart approaches like data-driven systems. He noted that failure to promote awareness of sustainability activities and other issues that may be on the consumer's mind is key to developing trust, which is necessary for the relationship's longevity. This perspective underscores the changes firms must make to sustain their competitiveness in a dynamically changing environment (Kabadurmus et al., 2023).

Similarly, Wang (2024) expands on the extent to which consumers embrace and influence green and digital service innovations further, conceptually examining the congruence between the business offering and consumers' concerns for sustainable and low-carbon solutions. While Kabadurmus et al. (2023) focus on the technological and operational changes necessary for such demands, Wang (2024) adopts a more strategic perspective, stressing the need to maintain open communication to enhance consumer confidence and commitment. Related to consumers' values is not only beneficial in the sense of developing and maintaining consumer relationships but also contributes to the building of a competitive advantage for an organization (Wang, 2024). All these viewpoints focus on the understanding that consumer awareness is important for sustainability and competitive advantage in the contemporary digital servitization environment.

Limited knowledge about how customer-centric factors (A3) and processes (B) have been linked to sustainable digital servitization exists. Customer feedback Loops and co-creation processes (A3) are necessary for the consecutive design frameworks and VR-enhanced user experiences (B2). In another paper, Bu et al. (2021) explain how feedback from users' interaction with the VR systems contributes to the continuous enhancements of smart PSS design. Customer interactions with VR platforms are a valuable real-time source of information on users' preferences, and such information can be decisive in enhancing the functions offered and the satisfaction levels noted. This feedback cycle promotes a longer lifespan for products because their constant revision in response to use experiences results in less destruction of resources.

Kabadurmus et al. (2023) emphasize that consumer awareness (A3) of product attributes, such as freshness and quality, drives the adoption of data-driven technologies (B2) like smart packaging. These systems rely on sensor data to control product quality and offer valuable updates to the consumer since the consumers expect products to be sustainable and informed in real-time. There is a strong linkage between A3, digital customization for sustainability, and B3, customer-centric design for sustainability, to create sustainability of smart product-service systems (PSS).

According to Chang et al. (2024), smart PSS uses IoT and data analytics to deliver digital customization to meet customer's needs. This customization also improves customer experience by increasing product durability, ultimately reducing resource consumption, making this change sustainable. Bu et al. (2021) note that feedback from the users (A3) promotes the effective implementation of iterative design (B3), which helps the developers to improve the smart PSS solutions depending on the real-life information and make the outcome more in line with the customer as well as sustainable requirements. For instance, VR-supported systems integrate user-related and system-related data to optimize functions, improve usability, and guarantee flexibility (Bu et al., 2021).

Therefore, consumer awareness and expectations (A3) affect collaborative circularity and lifecycle management (B5). As highlighted by Wang (2024), firms have integrated life cycle management that focuses on resource utilization to minimize waste due to consumer demands for sustainable green products. Such alignment guarantees that products and service-oriented strategic plans encompass sustainable development, not only in the face of environmental effects but also as a reflection of the consumer-driven trends towards green products and services (Wang, 2024). Co-creation (A3) is a prerequisite for designing and developing sustainable product-service systems (B5). Zhu and Hu (2021) note that co-creation brings together multiple stakeholders, including customers, into the process of developing Smart PSS to ensure that sustainability requirements are incorporated into products and services so that solutions that address sustainability concerns best align with customer needs are pursued (Zhu & Hu, 2021).
Customer-centric elements (A3), including feedback, co-creation, and consumer engagement, are critical drivers of sustainable digital servitization. They allow iterative

designing, lifecycle circularity, and sustainable product-service development focusing on customer needs, sustainability targets, and business outcomes. However, relatively few studies have probed these relationships in detail, indicating a call for more research to enhance and extend frameworks.

4.1.4 Market and Environmental Elements (A4)

Different authors have identified market and environmental aspects as key drivers of sustainable digital servitization as antecedents of organizational strategies. Kabadurmus et al. (2023) are concerned with how external shocks, like the COVID-19 pandemic, affect grocery supply chain continuity. Their study draws attention to the problems related to stock imbalances, increased levels of food waste, and the constantly changing consumer preferences. In response to these disruptions, the authors put forward a data-driven decision support system which includes smart packaging technologies. This system allows businesses to work flexibly in the unpredictable market environment while at the same time helping to work sustainably through minimizing waste and better stock control. However, while their approach effectively highlights the operational value of technological innovation during crises, it does not fully explore the long-term scalability of these solutions across diverse industries (Kabadurmus et al., 2023). Waste management is also underlined by them as another crucial activity within supply chains, though even more critical in the current unpredictable market environment. They support smart packaging technologies that can track the quality of food products and adjust the price to prevent food waste. This approach links sustainable development with economic goals by increasing the efficiency of resource utilization and extending product life cycles (Kabadurmus et al., 2023).

González Chávez, Despeisse, et al. (2023) broaden the discussion by highlighting that other factors in the external environment should also be considered to support sustainable digital servitization. Their work classifies regulatory frameworks, technological developments, and consumer preference changes as critical drivers of sustainable practices. Acknowledging these external pressures makes it easier for organizations to align their strategies with evolving market trends and proactively address sustainability challenges. Institutional and regulatory pressures further underscore the external forces shaping sustainable digital servitization. Chen et al. (2023) argue that governments and global regulatory authorities should play a critical role in sustainable development through policy frameworks and digital infrastructure development. For example, standards for energy efficiency and digital ecosystems incentivize organizations to transition toward sustainable operations. These frameworks require compliance and promote innovation because they provide a structured roadmap for achieving environmental objectives (Chen et al., 2023).

Similarly, González Chávez et al. (2024) explore the response of the maritime shipping sector to regulatory initiatives specifically concerning regulatory requirements for lower greenhouse gas emissions. They argue that such pressures force organizations to implement performance-based business models and integrate digital monitoring systems, creating competitive advantages to achieve cost savings and improved efficiency. The study also suggests the importance of multi-stakeholder collaboration to ensure these solutions work as designed (González Chávez et al., 2024).

Regulatory pressures (A4) drive the adoption of outcome-oriented models (B1) in sustainable digital servitization by creating a framework for compliance and innovation. According to González Chávez, Despeisse et al. (2023), sustainability-focused regulations require strategic integration of lifecycle control and resource management into an organization’s business model. These pressures force firms to move from a product-based perspective to an outcomes-based business model of value creation based on delivering sustainable results such as energy efficiency, waste reduction and circularity (González Chávez, Despeisse et al., 2023).

Market disruptions (A4), such as those caused by the COVID-19 pandemic, have accelerated the integration of data-centric service engineering (B2) in digital servitization. Kabadurmus et al. (2023) state that disruptions demand agile responses, prompting grocery retailers to adopt data-driven decision support systems that integrate smart packaging technologies to enhance supply chain resilience. These systems leverage real-time data on product conditions, such as freshness and shelf life, to adjust pricing and inventory management dynamically, reducing waste and improving operational efficiency (Kabadurmus et al., 2023).

These studies illustrate the complex interplay between market disruptions, waste reduction imperatives, external pressures, and institutional regulations in enabling sustainable digital servitization. The findings highlight the need to match the organization’s strategies with external demands. Subsequent research, however, could be more valuable in understanding how firms manage the inherent tensions between compliance, innovation, and sustainability objectives.

4.2 Studies on the sustainable digital servitization process

The section discusses the sustainable digital servitization process as a whole.

4.2.1 Business Model Innovation and Value Creation (B1)

Through the analysis of the selected literature for this study, business model innovation and value creation have been identified as a crucial process category. This category highlights the transformation process from product-centric to digitally enabled service-oriented models, focusing on sustainability outcomes. This process (B1) is further categorized into key themes: circular business model design, pay-per-use business models, integrated digital configuration, human-centred and resilient business models, dynamic and sustainable pricing models, and outcome-oriented models.

Several authors emphasize the importance of circular business models (CBMs) design in advancing sustainable digital servitization. However, the authors approach this concept from distinctive perspectives. Sjödin et al. (2023) emphasize the transformative role of AI-enabled mechanisms, like predictive analytics and resource optimization, in driving circularity. They state that these technologies facilitate the reuse, remanufacturing and recycling of materials, extending product lifecycles and improving operational efficiency. By applying circular business models (CBMs), companies may significantly reduce waste and achieve sustainability objectives (Sjödin et al., 2023). On the contrary, Kim et al. (2022) propose the sector-specific perspective by examining the circular business models in the electrical and electronic equipment industry. Their analysis emphasizes how strategies such as leasing, sharing platforms, and remanufacturing not only reduce environmental impact but also unlock economic opportunities. They highlight the role of digital tools in monitoring and optimizing resource loops, ensuring the durability and competence of products throughout their lifecycle (Kim et al., 2022). Bressanelli et al. (2024) offer the systemic perspective, evaluating digital servitization-based circular business models through simulation models. They emphasize the integration of pay-per-use schemes and long-lasting product designs, encouraging resource efficiency and lifecycle extension. Their findings demonstrate that combining circular principles with digital servitization creates a "win-win-win" scenario, benefiting the environment, society, and the economy simultaneously (Bressanelli et al., 2024).

Supplementing the perspective further, Menon et al. (2024) study the role of pay-per-use business models in aligning environmental and economic objectives. They emphasize how these models mitigate an upfront cost barrier for customers, thereby increasing accessibility to sustainable services. Instead, manufacturers are rewarded for durable, energy-efficient products by focusing on outcomes, not ownership. Lastly, they find that pay-per-use strategies let firms centralize maintenance and optimize operational efficiencies, allowing resource utilisation and carbon footprints. It enhances the competitiveness of manufacturers whilst resolving global sustainability challenges (Menon et al., 2024). Both studies emphasize the transformative potential of pay-per-use business models. While Bressanelli et al. (2024) emphasise operational and lifecycle implications, Menon et al. (2024) emphasize economic and strategic benefits. Both perspectives agree that pay-per-use models, supported by digital technologies, are crucial in advancing sustainable digital servitization.

Integrated digital configuration is another theme identified under the business model innovations and value creation category. De La Calle et al. (2021) highlight that integrated digital configuration drives innovation in digital product-service systems (PSS), especially within the capital goods industry. By integrating digital lifecycle management systems, businesses can enhance tracking across an entire product lifecycle, ensuring seamless service delivery and iterative improvements. This integration boosts customer satisfaction and aligns business operations with sustainability objectives. Through an optimization of lifecycle processes, organizations create value by delivering efficient, data-driven, and sustainable solutions (De La Calle et al., 2021).

Furthermore, Kolagar et al. (2024) emphasize the role of integrated digital configuration in ecosystem orchestration. It researches that firms adopting the multi-level (i.e. individual, organizational and ecosystem) framework in creating digital services in sustainability imperatives are effective. With technology like IoT and AI, businesses enhance stakeholder collaboration, which is essential for earning value by optimizing operations and producing sustainable results. Under this perspective, collaborative networks matter for amplifying the impact of digital configuration in business model innovation (Kolagar et al., 2024). However, Pan et al. (2019) highlight the application of integrated digital configuration within logistics and supply chain management, stressing its role in the smart PSS. It is argued that IoT and cyber-physical systems enable intelligent decisions and resource optimization, improving supply chain efficiency and reducing waste. By integrating digital tools into logistical operations, businesses can address the supply chain complexities and create value through improved asset utilization and environmental sustainability (Pan et al., 2019).

Nicoletti and Appolloni (2023) and Kumar Jena and Singhal (2023) provide complementary perspectives on human-centred and resilient business models in relation to different but closely implicated aspects. Artificial intelligence plays an important role in developing such models that are adaptable and stakeholder-focused and designed both to complement market disruptions and support societal goals

(Nicoletti & Appolloni, 2023). This approach improves service delivery while business operations align with broader societal goals, including environmental and social sustainability (Nicoletti & Appolloni, 2023).

On the contrary, Kumar Jena and Singhal (2023) examine the use of dynamic and sustainable pricing models in the digital supply chain. Thus, they assert that firms can coordinate economic, social, and environmental goals through digitalization and sustainability efforts in pricing strategies by using real-time data analytics to build up price decisions to maximize supply chain profitability while achieving sustainability purposes. Besides, such models benefit companies in terms of competitiveness and the ability to dynamically change prices based on market demand, resource, and sustainability metrics. Economic performance is supported by sustainable pricing models, aiming at balanced environmental stewardship and consumer value creation (Kumar Jena & Singhal, 2023).

Several studies indicate that models/strategies based on customer sustainability outcomes are critical for consistently aligning customer sustainability goals and business operations (González Chávez, Despeisse, et al., 2023; Kolagar et al., 2024). It uses sophisticated digital tools like AI-generated analytics to track performance metrics, optimise processes, and optimise long-term environmental benefits. By integrating outcome-based strategies, manufacturers can holistically manage customer operations to make sustainability embedded in the whole value chain (Kolagar et al., 2024). This viewpoint is further supported by González Chávez, Despeisse, et al. (2023), who explain that companies use the Sustainability-as-a-Service frameworks to align outcome-based objectives with sustainability imperatives. However, through digitally enabled solutions, organizations can improve resource efficiency and their carbon footprint, making it possible to build stronger customer relationships through transparent and measurable sustainability outcomes González Chávez, Despeisse, et al. (2023).

4.2.2 Technology Integration and Digital Transformation (B2)

Research has been dedicated to integrating data-centric service engineering within sustainable digital servitization in recent years. Opazo-Basáez et al. (2018) examine the digital and green servitization in the automotive sector and its decisive role of data-centric approaches which promote operational efficiencies and sustainability. Lastly, they describe how data-driven insights can help inform organizations' decision-making to optimise resources and improve productivity. On the other hand, they argue that combining these strategies has benefits because aligning operational performance with environmental goals gives manufacturers competitive advantages (Opazo-Basáez et al., 2018). Kabadurmus et al. (2023) expanded on this perspective and proposed a data-driven decision support system (DSS) for smart packaging use cases in grocery supply chains during crises like the COVID-19 pandemic. Data's dynamic nature was evidenced in how pricing strategy and inventory turnover can be dynamically adjusted, and food waste can be reduced. Shaped by data-centric approaches, this real-time adaptability is crucial to operational resilience and sustainability in managing perishables during market disruptions (Kabadurmus et al., 2023).

From a manufacturing perspective, Arioli et al. (2023) present data-centric service engineering for designing smart product service systems (PSS). Instead, they take the stance that continuous data collection and analysis can improve service offerings on an iterative basis. Along with supporting performance optimization, this methodology enables product life cycle management to track sustainability goals by minimizing waste and maximizing resource efficiency Arioli et al. (2023). The viewpoints demonstrate the need to use data to improve performance, increase sustainability, and respond to dynamic market conditions.

Other important processes in digital servitization are the combined aspects of digital lifecycle monitoring and management for seamless digital tracking and optimization of products from the cradle to the grave. Several of these authors offer complementary views of this process. Kruschke et al. (2023) discuss the need to adopt Life Cycle

Assessment (LCA) methodologies into the architecture of smart Product-Service Systems (PSS). By coupling LCA databases with system architecture, organizations can proactively assess the environmental impact of operations at the design phase. It encourages sustainability by identifying key areas, allowing the decision-making process to focus on ecological factors. Moreover, they argue for using comprehensive system boundaries, i.e., Cradle-to-Cradle frameworks, to exploit the circular economy principles in lifecycle management fully (Kruschke et al., 2023).

Similarly, sustainability within smart PSS frameworks can be evaluated by proposing a multi-criteria decision-making approach. To address the complexity and uncertainty of decision-making in early design stages, they emphasize using tools like the Best Worst Method (BWM) and TODIM (an acronym in Portuguese for Interactive and Multi-Criteria Decision Making). Their methodology facilitates a more comprehensive understanding of lifecycle performance, enabling a balanced consideration of economic, environmental, and social factors to ensure that products and services effectively achieve sustainability objectives (Liu et al., 2020). Furthermore, Wu et al. (2022) offer insights into applying conceptual modelling techniques in lifecycle management. They propose using the TRIZ function model to design a smart PSS that combines intelligent products and services to ensure continuous improvement in service delivery by integrating stakeholder feedback and operational data. This enhances adaptability and highlights the value of real-time monitoring and proactive interventions in maintaining product and service quality throughout their lifecycle.

Liu et al. (2020) further extend the same perspective by evaluating the sustainability within smart PSS frameworks with a multi-criteria decision approach. To handle the complexity and uncertainty of decision-making in early design stages, they support using tools such as the Best Worst Method (BWM) and TODIM (a Portuguese acronym for Interactive and Multi-Criteria Decision Making). A more comprehensive understanding of lifecycle performance is facilitated; such balanced methodological consideration of economic, environmental and social factors yields an effective assessment of products and services to achieve sustainability objectives.

Wu et al. (2022) further offer a view on applying conceptual modelling techniques in lifecycle management, integrating stakeholder feedback and operational data for smart PSS design using the TRIZ function model to guarantee continuous improvement in service delivery involving intelligent products and services. It also improves the adaptivity and the need for real-time monitoring and proactive interventions in achieving product and service quality during their whole life cycle (Wu et al., 2022).

Building upon the work of Arioli et al. (2023), the SEEM-Smart methodology emphasizes continuous refinement and the testing of service components throughout the product life, as the issue is discussed further into the technology integration and digital transformation in sustainable digital servitization. The iterative design framework can enhance efficiency and sustainability by minimising design-related waste and optimising resource utilization. Furthermore, this process increases the flexibility to respond to customers' changing needs (Arioli et al., 2023).

Similarly, Bu et al. (2021) also provide evidence that using VR-enabled platforms enables businesses to integrate customer needs utilizing technology into the design and delivery of the products to improve customer satisfaction and engagement. They have shown how real-time feedback and user-generated data can be used within an iteratively improved service through a case study of a VR-enabled rowing machine. Virtual Reality (VR) provides data-driven insights into user preferences while helping to personalize the service experience by reducing missing information and offering virtual experiences (Bu et al., 2021). Nevertheless, they concentrate on rowing machines, thus restricting the app's (general) disability beyond different industries. Vaillant and Lafuente (2024) also explored that integrating digital technologies increases a company's ability to monitor, control and optimize the allocation of resources successfully to achieve sustainability goals (Vaillant & Lafuente, 2024).

4.2.3 Service Design and Customer-Centric Innovation (B3)

The third category derived from the assimilated literature is service design and customer-centric innovation. Thus, we identify the following themes from the process category: customer-centric design and smart service development, digital interaction channels and service innovation, and collaborative and iterative design frameworks.

Bu et al. (2021) examine the customer-oriented approach within the framework of smart product-service systems (PSS) regarding medication management systems for elderly users. In the authors' view, user-oriented initiatives improve the effectiveness and usability of the services. The specific customer pains tackled by such services increase satisfaction and can advance resource utilization and achieve other sustainable objectives. Building on this line of thinking, Münch et al. (2022) take this customer-orientation perspective one step further by adopting socio-technical systems theory, where the authors posit that both the social and technical context, understanding user behaviour and embracing digital tools strengthen the services delivered and allow firms to provide better and more effective solutions. According to their arguments, customer-oriented design implies organizational flexibility and technological advancements to be most effective (Münch et al., 2022).

Chang et al. (2024) expand this view and focus on digital customization for customers' benefit as a key to sustainability within smart PSS. They contend that given the fact that services involve the use of resources in order to meet particular client needs, the idea of customized services minimizes the wastage of resources. Companies applying technology to meet customer needs can simultaneously have societal benefits and economic advantage goals (Chang et al., 2024). De La Calle et al. (2021) sources consider a position for the service design in the capital goods industry. Further, it is stated that using customer feedback guarantees service quality in the sustainability context of smart PSS. That is to say, any optimizing feedback loop boosts customers' expectation requirements and serves environmental goals (De La Calle et al., 2021).

Instead, Pirola et al. (2020) explore service development processes emphasising the circular economy. Here, it is important to highlight that incorporating reuse and remanufacturing into service design would be fundamental and integrating smart technologies into service design and delivery can allow a business to run effectively while obtaining sustainable results (Pirola et al., 2020).

According to Münch et al. (2022), new digital interaction channels improve companies' functioning in digital servitization. Such channels are helpful in smart PSS since they allow effective interaction between the service provider and the customer. Among such channels, websites, mobile applications, and systems of the IoT kind are notable; they enable businesses to collect information on the activity and preferences of the user in real-time. However, executing these systems is relatively challenging because of data and security implications. The researchers highlight the socio-technical systems approach, meaning that technologies and organizational changes must be integrated to pursue the best outcomes (Münch et al., 2022).

A key statement made by GÜR (2023) is that service innovation is predicated on using digital technologies. He took a more focused approach within a sector and looked at service innovation within the fashion Industry. To him, servitization in this industry has gone beyond the conventional product lines; it has embraced service support such as customer feedback and tailored services. IoT, big data analytics and cloud computing technologies are central to changing the landscape and providing businesses with the tools to create adaptable and sustainable service systems. Not only do these innovations change what customers experience and improve how businesses operate, but they also serve the purpose of helping businesses drive environmental sustainability, such as minimizing waste or conserving energy (GÜR, 2023).

The last theme under the service design and customer-centric Innovation process is collaborative and iterative design frameworks. Ries et al. (2023) developed an impact-oriented framework that connects business model properties to sustainability outcomes through a multi-step approach: design, cause and effect. This framework makes it possible for an organization to systematically improve the management of its processes by following feedback loops, making it effective in mitigating sustenance goals. In parallel, Arioli et al. (2023) proposed the SEEM-Smart approach, stressing the test and evolution steps during the product lifecycle stage. They emphasise the applicative advantages of reducing waste and improving resource utilisation by constant data acquisition and data analysis. This approach also improves the quality of services rendered in each iteration and commensurately with the changing customer requirements and sustainable development goals (Arioli et al., 2023).

4.2.4 Digital Ecosystem Collaboration and Supply Chain Transformation (B4)

Digital ecosystem collaboration and supply chain transformation processes allow organizations to leverage flexibility in business and the environment in line with sustainability. The study by Behl et al. (2024) concentrates on GSCMP in a servitized environment, showing the effectiveness of gamification in promoting goal setting, stakeholder management, and digital initiatives in the supply chain by incorporating game-theoretic design elements. In this perspective, Jankovic-Zugic et al. (2023) analyze the extent and the way automotive manufacturers pursue digital servitization by embedding digital technology into their supply chain. The authors use Social Network Analysis (SNA) to show the connections between the manufacturers and suppliers, showing that digital transformation enhances interaction, resource exchange, and effectiveness of stakeholders. Digital applications facilitate timely data exchange, enhance business decisions on operations and guarantee operational continuity in the face of disruptions in supply systems, as witnessed in COVID-19 (Jankovic-Zugic et al., 2023).

Li et al. (2021) offer their view on collaboration by adding that it can be improved by using more open and unalterable data. This makes stakeholders trust each other, making it easier to coordinate and ensuring that everyone is held responsible. Furthermore, IoT sensors enhance resource management, which leads to a sustained supply chain (Li et al., 2021). Upadhayay et al. (2024) point out that digital platforms facilitate innovation intensity through collaborative ecosystems and enhance firms' ability to respond to circular economy transitions and dynamic markets. It also stresses the need to develop organizational learning capabilities and modulate dynamic capabilities so that firms may achieve the desired environmental and operational improvements. (Upadhayay et al., 2024).

According to Chen et al. (2023), value co-creation is brought to the foreground by drawing on digital customization in smart PSS. They argue that customization helps organizations create value with their customers by adapting to their needs and desires while improving operational and sustainable performance. Chen et al. (2023) have noted that in using-oriented PSS, value is co-generated through the provision of maintenance services using IoT sensor analytics to track the product performance and facilitate customization for enhancing its lifespan and minimizing product wastage and in result-oriented PSS, the provision of outcomes such as energy efficiency or optimization instead of the physical product. Customers and suppliers combine to pursue shared objectives, for instance, cutting down on expenses or lowering environmental impact (Chen et al., 2023).

Kolagar (2024) offers a more general view of value co-creation by discussing ecosystem orchestration in digital servitization. In this paper, the authors examine Swedish manufacturing firms and find from a configurationally perspective that ecosystem orchestration, the coordinated engagement of multiple stakeholders, results in increased levels of industrial sustainability. They stress that the proper match of stakeholder goals, the implementation of AI-based optimization, and the orientation on outcome-based solutions are pioneering success factors of value co-creation. These aspects also indicate the need for an overall conductor to negotiate the roles, responsibilities, and risk-reward allocation among players who all stand to gain. The configurational approach shows that it is possible to observe many ways of attaining sustainability, indicating that organizations should act more flexibly in large ecosystems and change their strategies accordingly (Kolagar, 2024).

Smart PSS in logistics facilitates stakeholder communication and interaction, allowing vertical and horizontal integration, according to Pan et al. (2019). They also pointed out that vertical collaboration enhances the analysis and anticipation of customer needs rather than horizontal connection that enables the sharing of resources between rivals. Together, these approaches help effectively use resources and improve service delivery in logistics networks. Such a symbiotic advancement of logistics enabled by smart PSS also augments the prospects of new forms of logistics provision, including pay-per-use services or plug-and-play formats which foster flexibility and modularity in logistics systems (Pan et al., 2019).

Alcayaga and Hansen (2024) have recently presented an activity system that includes data exchange through IoT to enhance cooperation between the actors. They argue that the firms can apply circular approaches such as remanufacturing and recycling through interconnectivity. They noticed that smart use and circular activity sets are at the micro level of activities where stakeholders' operations are integrated into all the product life cycle stages (Alcayaga & Hansen, 2024). Their studies focus on individual processes within circular systems, while the study by Kolagar (2024) describes the interrelatedness of an ecosystem focusing on the orchestrator of multi-actor collaborations, as discussed above.

Several studies underscore the importance of managing a sustainable supply chain to achieve the objectives for sustainable digital servitization. According to De La Calle et al. (2021), digital product-service innovation (PSI) supports supply chain coordination in achieving sustainability. This is realized mainly through supply chain integration (SCI), which connects the internal activities within organizations and extends the relationships with external actors such as suppliers and customers (De La Calle et al., 2021).

Internal Integration ensures the collaboration across the various functions in a firm that results in a streamlined process and information sharing with external integration (building good relationships with suppliers and customers) to co-create value focusing on operational efficiencies and satisfying customer needs. Further expanding on this view, Kumar Jena and Singhal (2023) delve into green innovation and corporate social responsibility, i.e., CSR integration within competitive supply chains. They present an IoT Big Data Analytics Supply Chain Optimization framework to leverage Economic vs Environmental sustainability harmony in supply chain operations. Additionally, they maintain that collaborative models hold great importance in unbalancing manufacturer-retailer power dynamics to increase profits and sustainability. CSR should be integrated into the digital strategies of companies so that they have benefits in competitive markets concerning sustainable supply chain models (Kumar Jena & Singhal, 2023).

4.2.5 Sustainability and Circular Economy Integration (B5)

The last category in digital servitization for sustainable processes embeds sustainability with circular economy, which shows how important it is to embed sustainability strategies into digital servitization processes as circular economy principles. Broadly related and interlinked themes have been addressed in the literature under this process category. Digital servitization and Circular Economy paradigms have been critical concepts of collaborative circularity and lifecycle management. Alcayaga and Hansen (2024) urge to focus on a transformative role of digital servitization in nurturing closed-loop value cycles by leveraging smart product-service systems (PSS) and Internet of Things (IoT) networks.

The funnel framework of the product lifecycle identifies 20 micro-level activities in product lifecycle stages, arranged into smart use, circular and cross-strategy sets. This approach is conducive to organizational flexibility, nurturing boundary-spanning cooperation paradigms across stakeholders and stimulating innovation in circular systems (Alcayaga & Hansen, 2024). Halstenberg et al. (2021) expand on this by investigating the significance of knowledge transfer for smart-circular PSS implementation. The authors argue that sustainable circularity requires systemic stakeholder coordination, focusing on maintenance, repair, reuse, remanufacturing, and recycling strategies. By integrating model-based systems engineering (MBSE) with real-time lifecycle data sharing, the study underscores how businesses can align their practices with the United Nations Sustainable Development Goals (SDGs) (Halstenberg et al., 2021).

Kim et al. (2023) further contextualize collaborative lifecycle management within the context of Industry 4.0 for these findings; they shed light on the power of big data analytics, digital twins, and IoT in optimising lifecycle management processes. Instead, their work focuses on developing shared platforms that bridge Sectoral goals to drive beneficial environmental-economic-social synergies. The authors underscore that correlating advanced digital tools can decrease sustainability risks and enable inter-org collaboration (Kim et al., 2023).

Taking it further, Li et al. (2021) suggest a data-driven and possibly reversible smart PSS framework. They focus on the 4R strategies as a backbone to move from linear to circular systems, redesign, remanufacturing, reuse and recycling. The paper thus underscores the transformative power of advanced digital tools (IoT, big data analytics) in value chain optimization throughout the lifecycle. Their work suggests that incorporating cyber-physical resources will improve resource productivity at a development stage and ensure affordable decision-making along the entire lifecycle of physical goods or services.

From an industrial view, Zheng et al. (2020) claim that the sustainable industrial smart PSS (ISPSS) is a kind of lifecycle engineering and operation smart planning for embedding sustainability. Their concept of closed-loop smart design incorporates reversibility principles from the outset, focusing on design-for-reuse, disassembly and reconfiguration. Also, they stress the significance of cyber-physical resource allocation to be re-used effectively. They also emphasize stakeholder-centred adaptability, indicating that the scalability of sustainability demands only makes it possible with true flexibility and extended lifespans for products and services (Zheng et al., 2020).

Across these perspectives, a common theme is the centrality of reversible and circular strategies. Reversibility ensures that tangible and intangible resources are used in different lifecycle stages to reduce waste and environmental impact. Simultaneously, the latest digital technologies, such as IoT, AI, and big data analytics, facilitate real-time decision-making and resource optimization, which are necessary for effective circularity. All three studies emphasize the imperative of stakeholder integration and the grounds on which co-creation and adaptability drive long-term sustainability outcomes.

The development of sustainable PSS is a critical juncture at the nexus of digital technologies, service innovation, and sustainability principles. Researchers in different industries have explored how smart PSS could be used for operational efficiency, stakeholder collaboration, and environmental stewardship toward an integrated approach to addressing the modern sustainability challenges.

Li et al. (2021) assert that blockchain and IoT are transformative in developing smart PSS for prefabricated housing construction (PHC). Their smart platform relies on Cyber-Physical Systems (CPS), Buidling Information Modeling (BIM), and distributed ledger technologies to address inefficiencies in supply chains and poor interoperability. It promotes lifecycle management through real-time data sharing and stakeholder collaboration to minimize energy consumption and carbon emissions. This approach makes smart PSS a robust framework that integrates operational efficiency with sustainability in complex industrial systems (Li et al., 2021).

GÜR (2023) discusses how servitization and smart technologies aim for sustainability in the fashion industry. Smart PSS converts the traditional manufacturing approach into circular service-oriented models. Through IoT, cloud computing, and big data analytics, fashion companies can stretch product lifecycles, decrease waste, and promote collaborative consumption. These are changes that, according to him, need business operations to fit into global sustainability goals, as service innovation ought to be something beyond financial performance and should yield environmental and social value (GÜR, 2023).

Opazo-Basáez et al. (2018) examine the co-implementation of green and digital servitization in the automotive industry. Their findings suggest that coupling digital services, such as analytics through IoTs, with green initiatives (like emission reduction and recycling) enhances productivity and sustainability. They further comment that sequencing such strategies becomes important while suggesting that there should be an underlying basis between digital servitization and green servitization to maximize gains in productivity. This all-rounded approach helps automobile manufacturers achieve strict regulatory requirements and support resource efficiency while maintaining a competitive advantage (Opazo-Basáez et al., 2018).

Wang (2024) extends this discourse by emphasizing the role of product creativity in linking green and digital service innovations with firm performance. Firms can create environmentally friendly and economically viable solutions by fostering product effectiveness and novelty. His framework highlights the synergistic effects of these innovations in addressing consumer demands for sustainability while building competitive advantage. The integration of digital tools and green strategies not only reduces environmental footprints but also catalyzes value-driven innovation, demonstrating the economic viability of sustainability efforts (Wang, 2024).

Zhu and Hu (2021) further deepen the discussion by proposing a co-creative framework for evaluating sustainable value propositions (SVPs) in Smart PSS. Their decision-making model, based on rough-Z-number-based DEMATEL, addresses the uncertainties inherent in stakeholder assessments. This framework facilitates lifecycle thinking and stakeholder collaboration by aligning economic, environmental, and social value dimensions. They argue that co-creation among stakeholders is pivotal for developing sustainable solutions, emphasizing the need for robust evaluation methods to guide innovation in diverse applications such as circular economies and smart systems (Zhu & Hu, 2021). These studies illustrate a cohesive vision of sustainable PSS as a transformative paradigm. The consistent integration of digital technologies, stakeholder collaboration, and lifecycle thinking emerges as a common thread across industries.

Environmental strategy and sustainability assessment themes explore how digital servitization and evaluation frameworks can enable green innovation and assess the sustainability of smart product-service systems (PSS). Both topics contribute significantly to understanding and operationalizing sustainable practices in modern business environments.

Lee et al. (2024) argue that digital servitization is a crucial enabler of green innovation by integrating digital tools into service systems to reduce environmental impact. They propose that a firm's dynamic capabilities, particularly absorptive and transformative capacities, play a central role in leveraging digital servitization to implement effective environmental strategies. Absorptive capacity enables firms to identify and assimilate external knowledge, while transformative capacity allows them to apply it creatively for organizational innovation. Together, these capabilities support the reconfiguration of business models toward eco-friendly practices and green innovation. The study highlights that firms with well-aligned environmental strategies and digital servitization approaches can enhance green innovation by fostering sustainable product designs, improving resource efficiency, and facilitating collaborative consumption (Lee et al., 2024).

Liu et al. (2020) focus on evaluating the sustainability of smart PSS using a novel decision-making framework that integrates rough set theory (RST), the Best Worst Method (BWM), and TODIM (a Portuguese acronym for Interactive and Multi-Criteria Decision Making). Their framework addresses the challenges of assessing the sustainability of smart PSS during the early design phase by incorporating criteria based on the triple bottom line (economic, environmental, and social dimensions). They emphasize that smart PSS combines smart products and e-services, enabling firms to provide personalized and interactive solutions while minimizing environmental and social impacts (Liu et al., 2020). The findings highlight that fostering absorptive and transformative capacities, aligning environmental strategies, and employing robust evaluation frameworks are essential for achieving long-term sustainability goals.

4.3 Studies on the linkage between the sustainable digital servitization process and its outcomes

The last literature group discusses the interconnectedness of digital servitization processes and their resulting diverse, sustainable outcomes.

4.3.1 Operational Efficiency and Financial Performance (C1)

This category contains studies linking sustainable digital servitization process conclusions to operational efficiency and financial performance. Predictive maintenance is the cornerstone of sustainable digital servitization, directly contributing to operational efficiency and cost reduction by minimizing unplanned downtime and optimizing resource use. Opazo-Basáez et al. (2018) illustrate the transformative potential of predictive maintenance in the automotive industry, highlighting its ability to leverage real-time data from interconnected systems to foresee and prevent equipment failures. This proactive approach not only ensures uninterrupted production but also extends the lifecycle of machinery, reducing overall maintenance costs and enabling a more efficient allocation of resources.

In contrast, Li et al. (2021) adopt the broader perspective, presenting the data-driven reversible framework that integrates predictive maintenance into sustainable Smart Product-Service Systems (Smart PSS). Their framework emphasizes the role of IoT-enabled sensors and machine learning algorithms in continuously monitoring equipment degradation and maintaining useful life, enabling precise, context-aware decision-making. While both perspectives underline the economic benefits of predictive maintenance, Li et al. (2021) further talk about its alignment with sustainability goals by highlighting its potential to optimize energy consumption and material usage in circular systems.

Bressanelli et al. (2024) noted that resource efficiency in the digital servitization-based circular business models (CBMs) can be enhanced through strategies like product lifecycle extension, reuse, and pay-per-use systems. These practices minimize material consumption and operational costs, creating a win-win situation across economic, environmental, and social dimensions. Sjödin et al. (2023) provide a complementary perspective by focusing on the role of artificial intelligence (AI) in optimizing resource allocation within CBMs. They emphasize AI's capacity to enable automation and augmentation in the resource management processes, like predictive analytics for waste reduction and energy efficiency. It reduces the operational costs and aligns with the circular principles by optimizing the use of materials and energy throughout the lifecycle.

Kolagar et al. (2024) add to this discussion by exploring how smart solutions, like AI-driven optimization and outcome orientation, enhance resource efficiency in industrial operations. Integrating digital technologies into servitization enables firms to dynamically respond to resource demands, reducing waste and maximizing economic returns. Meanwhile, Kumar and Sharma (2023) focus on the Industry 4.0 context for small and medium enterprises (SMEs), emphasising how digital transformation enables cost-effective resource management. By implementing IoT-enabled systems, SMEs can track and optimize resource use in real-time, which supports cost reductions and improves operational efficiency.

Kim et al. (2022) adopted the sectoral lens, investigating South Korea and Singapore's electrical and electronic equipment industry. They reveal that circular business models, like rental systems and modular designs, reduce resource dependency by facilitating product repair, refurbishment, and recycling. These strategies lower production costs while contributing to environmental sustainability. Finally, X. Li et al. (2021) proposed a data-driven reversible framework for sustainable Smart Product-Service Systems (Smart

PSS), highlighting an integration of cyber-physical resource management. Their framework enables real-time decision-making and lifecycle optimization, reducing material waste and operational inefficiencies, thereby lowering costs.

Cost reductions, resource efficiency, and the generation of new revenue streams are pivotal outcomes of digital servitization when embedded within sustainable business models. González Chávez, Despeisse, et al. (2023) explore a paradigm of "Sustainability-as-a-Service," highlighting how a servitized business model can faciliHisate the transition from linear to circular systems. By embedding sustainability principles at the core of their value propositions, organizations create opportunities for cost efficiency through waste reduction, resource optimization, and enhanced lifecycle management. For instance, leveraging digital tools and smart systems to track and optimize resource use helps minimize material waste while creating new service-oriented revenue models, like subscription services or outcome-based pricing.

GÜR (2023) emphasizes how Smart Product-Service Systems (Smart PSS) enable organizations to achieve economic and sustainability objectives in the fashion industry. By integrating digital technologies like IoT, RFID, and 3D virtual design, companies reduce production costs and material waste while enhancing customization and customer satisfaction. Innovations like on-demand manufacturing and virtual try-on systems optimise resource usage and open new revenue streams through pay-per-use or rental services. His analysis underlines that such service-based models facilitate the shift toward customer-centric and environmentally sustainable operations, highlighting their scalability across industries.

Halstenberg et al. (2021) highlight the crucial role of smart circular product-service systems (Smart PSS) in facilitating resource-efficient production. Companies can significantly reduce material usage and production costs by embedding circular economy strategies such as durable design, reuse, and refurbishment into early-stage product development. Integrating digital tools and knowledge-transfer systems further enables businesses to align resource allocation with real-time lifecycle data, enhancing overall system efficiency and sustainability. Jankovic-Zugic et al. (2023) discuss the implementation of Servitization 4.0 in the automotive industry, emphasizing its transformative impact on resource optimization and profitability. By leveraging digital technologies like IoT and AI, firms can optimize supply chain operations and reduce waste while creating new revenue streams through service-oriented models such as predictive maintenance and data-driven services. It fosters both financial growth and environmental sustainability.

Zhu and Hu (2021) explore the co-creative potential of Smart PSS in achieving lifecycle cost efficiency. Through stakeholder collaboration and advanced evaluation frameworks like DEMATEL, businesses can identify and implement sustainable value propositions that optimize resource use across the product lifecycle. It minimizes lifecycle costs while enhancing smart systems' overall performance and sustainability. Bag et al. (2024) introduce Smart Circular Product-Service Capabilities (SCPC) as a dynamic business model that reduces costs through waste management and optimized resource utilization. Their findings reveal that SCPC enables firms to improve financial performance by reconfiguring supply chain capabilities and adopting a "trash-to-treasure" approach to material reuse.

Mihardjo et al. (2020) argue that Green Information Systems (GIS) significantly extend product life cycles and reduce costs. By enabling firms to track and manage product usage patterns effectively, GIS supports maintenance and refurbishment activities, leading to prolonged product lifespans and reduced need for new production. This approach aligns cost savings with environmental sustainability.

The key outcomes of digital servitization, profitability and revenue growth are achieved through distinct yet interconnected approaches like dynamic pricing, green innovation, operational efficiency, and long-term business model resilience. Each perspective highlights a unique pathway toward enhanced profitability, reflecting the impact of digital servitization. Kabadurmus et al. (2023) focus on operational profitability through dynamic pricing and inventory management in grocery supply chains. By integrating smart packaging within the Smart Product-Service Systems (Smart PSS), firms dynamically adjust pricing based on product freshness, reducing food waste and optimizing inventory turnover. It ensures cost savings and improves profitability by addressing efficiency's economic and environmental dimensions.

On the contrary, Lee et al. (2024) highlight that digital servitization drives profitability through green innovation and enhanced market competitiveness. By adopting the IoT and cloud-based technologies, firms align their operations with sustainability objectives, fostering customer loyalty and opening new revenue streams. They emphasize that customers increasingly value eco-friendly innovations, enabling firms to differentiate themselves in competitive markets while achieving profitability through sustainable practices. Building on this, Xie et al. (2023) take the broader perspective by examining the integration of servitization and digitalization, highlighting their combined potential to enhance profitability and resilience. Transitioning from traditional product-centric models to service-oriented business models, like pay-per-use and subscription services, provides a continuous revenue stream while reducing operational costs. These models mitigate the risks of market fluctuations and offer long-term financial stability, showcasing the value of service delivery as a resilient revenue strategy.

Lastly, Menon et al. (2024) link profitability to operation efficiency by discussing maintenance centralization encouraged by servitization. By cutting down on energy use and minimizing waste, firms not only improve their cost effectiveness but also develop environmental value, which in turn are helpful to the increase of overall economic sustainability. This view also serves to appreciate the fact that there is a growing convergence between the economic and environmental interests of firms. Integrating advanced technologies within digital servitization offers firms the potential to generate new revenue streams while reducing operational costs. Various studies highlight different enablers and mechanisms driving this growth, illustrating the versatility of servitized business models in fostering innovation and market expansion.

Sjödin et al. (2023) highlight the transformative role of artificial intelligence (AI) in enabling circular business model innovation (CBMI). By leveraging AI's perceptive, predictive, and prescriptive capacities, firms can automate and augment resource management processes, leading to optimized operations and cost reductions. AI-enabled CBMs (e.g., autonomous solutions and optimization services) open new revenue opportunities by enhancing resource efficiency and extending product life cycles. This combination of automation and value co-creation with ecosystem partners allows firms to tap into previously inaccessible markets, particularly those focused on sustainable solutions.

Li et al. (2021) emphasize using blockchain and IoT in smart product-service systems (SPSS) within the prefabricated housing construction industry. Their findings reveal that integrating these technologies facilitates real-time data sharing and decision-making, improving supply chain efficiency and accuracy. By transforming supply chains into collaborative ecosystems, firms can innovate service offerings that cater to the specific needs of stakeholders. These innovations reduce costs, enhance operational efficiency, and create revenue-generating opportunities by providing tailored data-driven solutions.

Chang et al. (2024) explore how customization-oriented Smart PSS enable firms to penetrate new markets and increase profitability. Firms can design and deliver tailored offerings that meet individual customer needs by employing digital technologies like IoT and big data analytics. This customization capability fosters customer loyalty and satisfaction, positioning firms as leaders in niche markets. Furthermore, result-oriented Smart PSS, which delivers specific outcomes rather than products, enhances customers' value proposition, enabling firms to capitalize on high-margin service models.

The integration of digital servitization technologies into the organizational processes fosters both enhanced decision-making and process automation. This enables firms to address sustainability challenges, optimize operations, and deliver value more effectively. Insights from several studies highlight varied yet interconnected mechanisms through which digital servitization supports these advancements. For instance, González Chávez et al. (2024) argue that digital servitization leverages advanced data analytics to enable real-time operational metrics tracking, fostering informed decision-making in the maritime shipping industry. Integrating lifecycle data allows firms to address sustainability goals by proactively adapting their operations to reduce costs and environmental impacts.

Similarly, Li et al. (2021) present a novel multi-criteria evaluation framework tailored for Smart Product-Service Systems (Smart PSS). Their approach emphasizes that integrating rough set theory with decision-making algorithms allows businesses to reduce uncertainty and optimize resource allocation effectively. This facilitates better sustainability assessments and enhances operational outcomes in the early design stages of Smart PSS. Moreover, Kabadurmus et al. (2023) highlight the role of dynamic pricing mechanisms in grocery retail chains enabled by data-driven decision support systems. By analyzing product freshness levels in real-time, businesses can adjust pricing dynamically, reducing food waste and maximizing profitability. This application demonstrates the dual economic and environmental benefits achieved through data-driven automation.

Halstenberg et al. (2021) emphasize integrating circular economy strategies into Smart PSS design facilitated by knowledge-transfer frameworks. Automating routine lifecycle processes, such as maintenance and resource reuse, enables firms to align their operations with circular economy principles, reducing waste and enhancing efficiency. Additionally, Kruschke et al. (2023) discuss the application of Model-Based Systems Engineering (MBSE) in automating sustainability assessments within Smart PSS architectures. By integrating lifecycle assessment tools early in the design phase, firms can automate resource optimization decisions, reducing the need for manual interventions and improving long-term operational sustainability.

From the automotive sector, Opazo-Basáez et al. (2018) highlight how green servitization strategies, when coupled with digital tools, streamline processes such as predictive maintenance and energy management. This reduces resource wastage and operational downtime, enhancing sustainability and productivity.

4.3.2 Enhanced Collaboration and Ecosystem Synergies(C2)

Enabled by digital technologies, the interdependence among firms fosters value creation through integrated efforts across value chains and cross-industry innovation. Alcayaga and Hansen (2024) emphasize the role of smart circular systems in fostering integrated value chain collaboration by leveraging Internet of Things (IoT) networks. They argue that data-driven connectivity enhances transparency, enabling seamless interactions between stakeholders throughout a product's lifecycle. For instance, IoT-enabled tracking and diagnostics facilitate collaborative maintenance and reuse strategies, reducing inefficiencies and promoting circular economy practices. Kim et al. (2023) extend this discussion by describing how Industry 4.0 technologies, such as big data analytics and digital twins, enhance communication and coordination within value chains. Such technologies allow firms to transition from isolated operations to interconnected ecosystems, improving resource efficiency and customer satisfaction.

Chen et al. (2023) focus on the importance of robust digital infrastructure in building resilient ecosystems. Effective collaboration is contingent on shared platforms and tools that allow partners to co-create value. By aligning individual and collective goals through a digital ecosystem, firms can achieve operational synergy and unlock new growth opportunities. On the other hand, Kolagar et al. (2024) explore the orchestration of multi-level ecosystems, emphasizing that cross-industry partnerships are crucial for innovation in digital servitization. They identify ecosystem orchestration as a strategic approach where firms leverage diverse competencies and technologies from multiple industries to co-create tailored digital solutions. This collaborative effort enables firms to address sustainability goals while remaining competitive in a dynamic marketplace.

Paiola et al. (2021) emphasize the transformative role of digital technologies like the Internet of Things (IoT) in creating agile and interconnected networks. By enabling real-time data sharing and analysis across value chains, IoT fosters dynamic decision-making, which allows firms to respond promptly to disruptions, such as those experienced in supply chains during the COVID-19 pandemic. Jankovic-Zugic et al. (2023) further illustrate this point by discussing how adopting Servitization 4.0 principles in the automotive sector has strengthened relationships between manufacturers and suppliers. These relationships are reinforced through digital tools that improve transparency and allow quicker responses to external shocks, such as supply chain delays. This adaptability ensures that firms remain competitive despite changing external conditions.

Pan et al. (2019) provide additional evidence by focusing on smart product-service systems (PSS) in logistics. They argue that advanced logistics paradigms, such as the Physical Internet (PI), rely heavily on intelligent interoperability to ensure agility and flexibility in resource management. The ability of these systems to autonomously process information and adjust logistics operations in real-time is a game-changer for improving supply chain resilience and responsiveness.

Effective stakeholder engagement is pivotal in enabling mutual value creation in servitized ecosystems. Behl et al. (2024) explore that gamification can strengthen green supply chain management engagement. By fostering goal commitment among supply chain actors, gamification encourages collaboration and shared accountability, ultimately improving sustainable performance. Liu et al. (2020) highlight the integration of blockchain and IoT in prefabricated housing construction as a case study of stakeholder collaboration. By employing these technologies, their smart product-service systems connect diverse stakeholders, such as designers, producers, and assemblers, on a unified platform, facilitating better communication and mutual decision-making. This results in enhanced trust and co-created value across the supply chain.

Upadhayay et al. (2024) extend this perspective by emphasizing digital and green servitization synergies. They argue that stakeholder engagement is critical in aligning organizational learning capabilities with sustainability goals fostering technological innovation that benefits all parties involved. For instance, collaborative efforts between firms and their stakeholders lead to co-creating green technologies, further reinforcing mutual value creation.

4.3.3 Social Sustainability and Human Development (C3)

Sustainable digital servitization has proven instrumental in bridging gaps in service accessibility, particularly for underserved or geographically dispersed populations. According to Bressanelli et al. (2024), implementing servitized models in a circular economy allows companies to reach a broader customer base by offering subscription-based washing machines. These offerings lower entry barriers by shifting ownership from consumers to providers, democratizing access to essential appliances while promoting sustainable practices. Similarly, Kim et al. (2022) highlight how product-as-a-service approaches in Singapore and South Korea have enabled consumers to access cutting-edge technology without upfront ownership costs, fostering inclusivity while driving the circular economy in the electronics sector.

Digital technologies also enhance equality in accessing advanced services and products. Bressanelli et al. (2024) noted that Internet of Things (IoT) integration ensures remote monitoring and predictive maintenance, enabling even resource-constrained users to benefit from high-performing, energy-efficient appliances at reduced costs. Meanwhile, Kim et al. (2022) pointed out that digital servitization in South Korea leverages personalized services like home visits for equipment maintenance, which specifically cater to vulnerable groups such as elderly users, ensuring that they are not excluded from technological advancements.

In a broader sense, digital servitization enables social inclusion by involving users in co-creation. Chang et al. (2024) discuss how manufacturers integrate customer feedback in designing and customising smart product-service systems (PSS), ensuring that diverse needs are met efficiently. This collaborative approach enhances customer satisfaction and cultivates a sense of ownership and inclusion among end-users. Furthermore, De La Calle et al. (2021) illustrate that digital product-service innovation fosters stakeholder participation through data-driven feedback loops, especially in capital goods industries. These enable continuous refinement of service offerings, particularly beneficial for underrepresented communities that might otherwise lack access to high-quality solutions.

Sustainable digital servitization drives significant advancements in workforce skill development and job creation by reshaping traditional roles and enabling organizations to adopt innovative practices. Chang et al. (2024) also highlight that smart product-service systems (PSS) incorporate digital technologies like IoT and AI to customize services, creating opportunities for employees to develop advanced digital and analytical skills. This shift enhances individual career trajectories and contributes to organizational competitiveness by fostering a skilled, digitally savvy workforce. Similarly, González Chávez et al. (2024) describe the maritime sector's transition to servitized models, emphasizing the creation of high-value jobs related to data management, digital systems maintenance, and strategic decision-making, which are essential to support new business models.

Kolagar et al. (2024) extend the discussion by focusing on the ecosystem perspective, emphasizing the role of stakeholder inclusion in skill enhancement. Their study underscores the importance of collaborative efforts across organizations to provide employees with continuous learning opportunities, particularly in ecosystems driven by data-centric and digital solutions. It not only aligns with sustainability objectives but also ensures the adaptability of the workforce in dynamic environments. Additionally, Xie et al. (2023) stress that the integration of digital technologies within servitized ecosystems enhances employee expertise, enabling organizations to respond to market demands efficiently while fostering job satisfaction and retention

Sustainable digital servitization has shown significant potential to empower employees and enhance workplace safety by using smart systems and real-time data analytics. Opazo-Basáez et al. (2018) argue that digital servitization enables the integration of advanced monitoring technologies, which allow for better oversight of operations and create safer environments for workers through predictive maintenance and real-time feedback loops. These systems reduce the likelihood of accidents caused by machinery failures, fostering a safer workspace. Similarly, González Chávez, Unamuno, et al. (2023) emphasize the role of data-centric tools in optimizing workforce management. By automating routine tasks and equipping employees with user-friendly interfaces, digital servitization reduces mental fatigue and operational errors, thus empowering the workforce to focus on higher-value tasks. Bu et al. (2021) state that a user-centric smart system enhances safety and contributes to job satisfaction, as workers feel more in control of their roles and are better supported by technology.

The integration of digital technologies into servitized ecosystems contributes to the establishment of rigorous health and safety standards. Opazo-Basáez et al. (2018)

explored that digitalization enhances regulatory compliance by enabling detailed tracking and reporting of safety metrics. Implementing Internet of Things (IoT) sensors and automated alerts ensures that deviations from safety protocols are swiftly identified and addressed, further improving operational safety.

Sustainable digital servitization is critical in ensuring food safety and hygiene in consumer-facing contexts. Kabadurmus et al. (2023) describe how smart packaging systems with IoT-enabled sensors monitor food freshness in real-time. It reduces the risk of contamination by providing accurate data on storage conditions and product shelf life, thereby enhancing consumer trust and satisfaction. Such advancements address consumer concerns about health and safety and align with sustainability objectives by minimizing food waste through better inventory management.

Ries et al. (2023) discuss how sustainable smart product-service systems (PSS) embed safety and health considerations into product design and lifecycle management. By leveraging digital tools and smart technologies, organizations can preventively identify risks and tailor solutions that enhance user satisfaction while ensuring compliance with safety standards. The authors emphasize the potential for PSS to balance operational efficiency with societal impacts, fostering a safer and more sustainable consumer environment. González Chávez et al. (2024) underscore that the maritime sector benefits significantly from training initiatives that enhance digital skills, enabling employees to adapt to rapidly evolving technological landscapes. This fosters a workforce capable of managing sophisticated tools like digital twins and IoT systems, driving efficiency and innovation. Similarly, Xie et al. (2023) argue that digital literacy improves employee performance and enhances their capacity to engage in co-creation processes, leading to more resilient and innovative organizations. Integrating continuous learning into organizational strategies ensures employees remain relevant and proactive in addressing emerging challenges.

Li et al. (2021) emphasize the role of blockchain and IoT-enabled systems in fostering stakeholder collaboration within the prefabricated housing construction (PHC) industry. These technologies ensure accountability across the entire lifecycle by enabling real-time data sharing and transparent communication, enhancing decision-making inclusivity. The authors argue that such systems empower stakeholders to co-create sustainable solutions, reducing inefficiencies and improving overall trust among ecosystem actors. Kolagar et al. (2024) further extend this perspective by highlighting the importance of co-creation processes in aligning stakeholders toward shared sustainability objectives in industrial ecosystems. They underline that digital servitization fosters a collaborative environment where manufacturers and stakeholders jointly address challenges like resource optimization and lifecycle management.

Li et al. (2021) highlight how blockchain and IoT technologies in the Smart PSS foster transparency and equitable decision-making throughout a product lifecycle. Meanwhile, Kolagar et al. (2024) highlight the importance of co-creation in aligning stakeholders toward shared sustainability goals. These approaches enhance trust and ensure collective accountability. González Chávez, Despeisse, et al. (2023) link stakeholder collaboration to increased trust, safety improvements, and job creation, noting how digital servitization reduces uncertainties and facilitates smoother interactions. Likewise, Halstenberg et al. (2021) discuss how the stakeholder input in Smart PSS design promotes consumer engagement in sustainable practices by embedding eco-friendly value propositions.

Sustainable digital servitization and smart systems significantly contribute to societal resilience and well-being by enabling adaptability during crises and improving safety in daily life. Smart Product-Service Systems (PSS) foster resilience by providing real-time responses and dynamic resource coordination, allowing businesses to navigate disruptions effectively (Wu et al., 2022). Similarly, integrating blockchain and IoT technologies into supply chains ensures transparency and operational continuity, particularly during crises like the COVID-19 pandemic (Li et al., 2021). Upadhayay et al. (2024) further emphasize the role of green and digital servitization in enhancing organizational learning and fostering dynamic capabilities, enabling firms to innovate and remain agile in volatile markets. In addition to crisis management, Wu et al. (2022)

propose an Extended Collision Warning System (ECWS) that leverages sensors and intelligent services to reduce traffic accidents proactively.

4.3.4 Environmental Sustainability and Circular Economy Outcomes (C4)

The last category under the outcomes looks closer at how a sustainable digital servitization process can help achieve environmental sustainability regarding energy efficiency, resource optimization, and support for a circular economy. Innovative business models and technology-enabled advancements create new possibilities to build ecologically sustainable structures and mitigate adverse environmental effects.

Digital servitization has hence been established as a novel solution to energy efficiency and reduction of carbon impacts across industries. With the help of IoT, AI, analytics, and smart technologies, companies can enhance energy utilisation and logistically improve their performance. These innovations offer timely information and recommendations that help with accurate energy use and minimize wastage and resource-intensive processes. For instance, lifecycle assessments (LCA) applied to industries have shown that using LCA decreased energy consumption by up to 12% and reduced emissions by as much as 40% (Kruschke et al., 2023). Likewise, the application of smart logistics with which data is used in optimizing the supply chain has reduced waste and emissions, especially in industries involving transportation, primarily in manufacturing automobiles (Jankovic-Zugic et al., 2023; Wang, 2024). These findings indicate that digital servitization allows firms to operate efficiently and progress towards sustainability.

Further, the environmental impact of digital servitization is not only limited to energy efficiency but also to a range of pathways aligning well with circular economy strategies. These aspects, integrated through smart product-service systems, not only minimize carbon emissions but also optimize resource utilization through the reduction and recycling of wastage (Li et al., 2021; Menon et al., 2024). It strengthens organizations' strategic position and capacity to align with regulatory and market expectations about sustainable practices while keeping cost concerns in check in the short and long term (Walk et al., 2023; Wang, 2024). Overall, digital servitization is a key enabler of global carbon neutrality outcomes and creates positive synergies between ecology and economy through technology solutions.

Various authors have discussed resource efficiency and waste reduction to uncover their importance in achieving sustainability goals. Building upon Kim et al. (2022), the influence of digital servitization is discussed in the electronics sector concerning the role of manufacturers' refurbishment and recycling programs to minimize material wastage. They stress that circular business models supported by smart technologies provide a sound structure for controlling resource loops (Kim et al., 2022). Similarly, Li et al. (2021) and Zheng et al. (2019) point out that circular resource optimization can be achieved through Smart Product-Service Systems (Smart PSS) as these systems improve asset management and increase resource monitoring and foresight for circular material use (Li et al., 2021; Zheng et al., 2019).

Similarly, Chang et al. (2024) examine how customization practices within Smart PSS models help reduce waste since consumption is flexibly adjusted depending on user needs to ensure efficiency of material consumption. GÜR (2023) supports this view by looking specifically at the extended fashion supply chain where the adoption of Smart PSS has helped to enhance efficiency and minimize material loss through new service-oriented perspectives. Sjödin et al. (2023) take a broader perspective on this phenomenon, arguing that AI leads to circular business model innovations. They maintain that optimization solutions developed from artificial intelligence do more than rely on automation to utilize resources; they also rely on the recycling and waste reduction scheme through modelling and monitoring. Likewise, Li et al. (2021) review the use of digital twin technologies, which allow the virtual simulation of the product life cycle, allowing companies to identify inefficiencies and optimize resource utilization efficiently.

In improving recycling and waste management, Zheng et al. (2020) call on Internet of Things (IoT)-based tracking devices to optimize recycling processes and boost resource recovery. They have suggested that smart technologies make it easy to sort waste to ensure that recyclable materials feed back into production processes. However, Kabadurmus et al. (2023) shared innovations in the food industry, pointing out smart packaging as the key to minimizing food waste and improving stock management.

Adopting circular economy principles and lifecycle management has become increasingly important in reaching sustainability within digital servitization frameworks. By providing a platform for integrating digital technologies throughout lifecycle processes, they enable more efficient reuse, remanufacturing, and recycling, thus reducing waste and improving sustainability. According to Alcayaga and Hansen (2024), IoT-enabled ‘smart circular systems’ enable companies to track, analyze and optimize product lifecycle to enhance resource efficiency across industries. As noted by Zheng et al. (2020), the industrial smart product-service systems (ISPSS) are critical in facilitating closed-loop lifecycle management with advanced information and communication technologies (ICT) that create both environmental and economic benefits.

Servitized business models, such as pay-per-use and subscription systems embedded with circular economy principles, offer avenues to extend product lifespan via reuse and refurbishment. Bressanelli et al. (2024) noted that such a model decreases material consumption and promotes closer adherence to sustainability goals in electronics and manufacturing. On the same note, Kim et al. (2022) present a circular economy approach to managing waste electrical and electronic equipment (WEEE) utilizing digital servitization to promote systemic efficiency and reduce environmental burden. Lee et al. (2024) also have the same perspective and state that Smart Product-Service Systems (Smart PSS) are critical for achieving such outcomes through eco-design and lifecycle analysis. This is supported further by the view of Liu et al. (2020), who recommend the early evaluation of Smart PSS solutions to uncover and avoid potential sustainability challenges and specify the vital role of ‘lifecycle’ thinking in sustainable product development.

In addition, Smart PSS models have also been shown to be associated with lifecycle sustainability and value co-creation and customization. According to Chang et al. (2024), the combination of the ability to provide digital customization of products and services can be tailored to specific user needs, and waste and resource inefficiencies can be reduced. Mauersberger et al. (2023) extend this view by proposing that digital servitization-based lifecycle management initiatives can optimize economic and environmental performance by enhancing customer satisfaction at the same time.

The involvement of technology in environmental improvement is no longer novel, and digital servitization has proven its success by enhancing resource optimization, reducing waste, and promoting sustainable practices. Artificial intelligence (AI) is known for optimising resource usage and enabling circular loops, such as reducing, reusing, and recycling materials. Sjödin et al. (2023) identified AI capacities as perceptive, predictive, and prescriptive, allowing manufacturers to identify inefficiencies and create innovative circular business models. These AI-driven solutions improve resource efficiency and automate and augment decision-making processes in support of long-term sustainability (Sjödin et al., 2023).

Similarly, the Internet of Things (IoT) also plays an important part in remote monitoring functionality, which helps eliminate waste and extend the lifespan of products through optimization of maintenance activities. Arioli et al. (2023) describe that IoT platforms enable real-time data collection and analysis to improve lifecycle management and, where required, proactively avoid inefficiencies. This perspective is further aided by Li et al. (2021), who argue that IoT-integrated smart systems in the construction sector lower waste through the connectivity and coordination within the supply chains.

According to Kolagar et al. (2024), real-time monitoring systems are critical in saving energy, and this supports resource-efficient practice. Manufacturers can relegate the continuous optimization of production cycles to the background using services like cloud computing and the industrial IoT, thus deriving extensive environmental benefits. This also aligns with the findings of Chen et al. (2023) that digital servitization connects green management practice with technological innovations to simultaneously reduce energy use and improve production efficiency (Chen et al., 2023; Kolagar et al., 2024).

4.4 Overall Evaluation

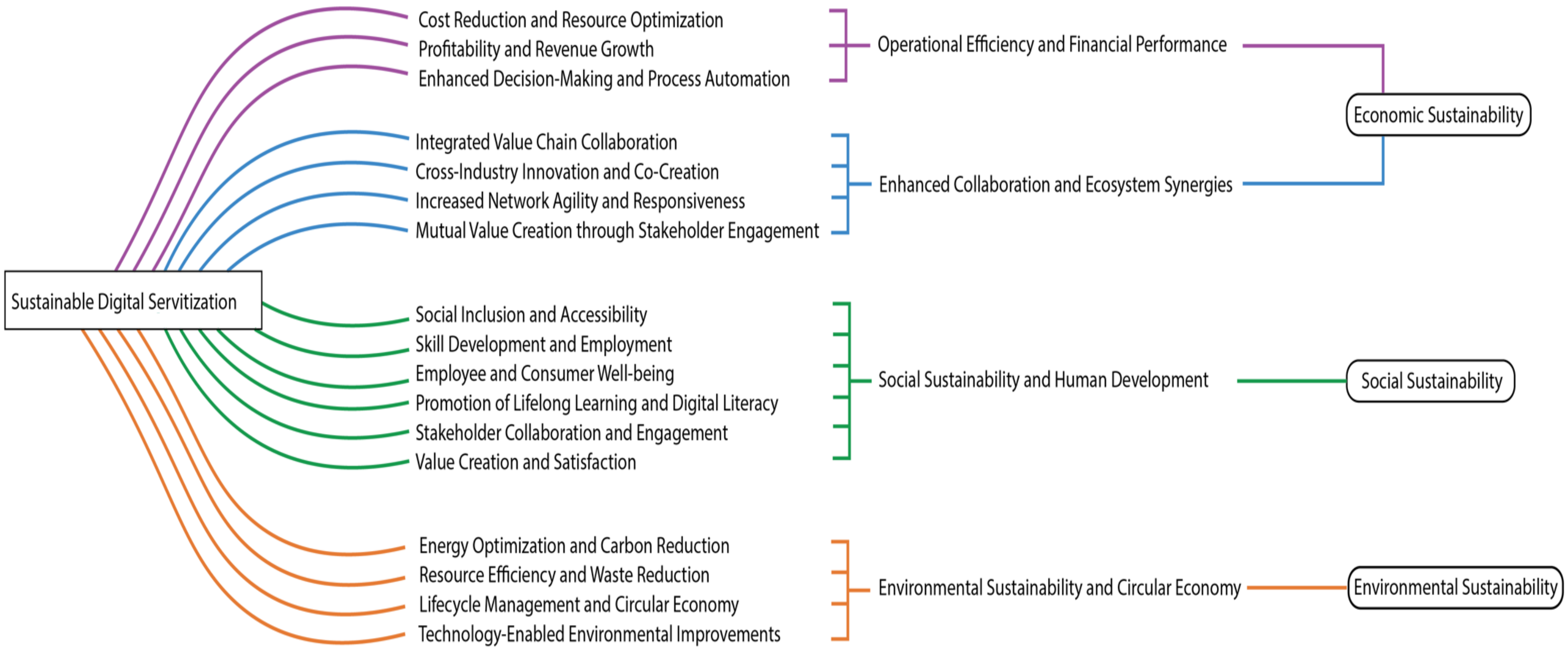
Digital servitization is a transformative approach that integrates digital technologies into traditional product-based business models, enhancing operational efficiency and financial performance while fostering social and environmental sustainability. Predictive maintenance, enabled by the real-time data from interconnected systems, minimizes unplanned downtime and extends a machinery lifecycle, reducing maintenance costs and optimizing resource allocation (Li et al., 2021; Opazo-Basáez et al., 2018).

Resource efficiency is further enhanced through strategies like product lifecycle extension, reuse, and pay-per-use systems, which minimize material consumption and operational costs, creating a win-win situation across economic, environmental, and social dimensions (Bressanelli et al., 2024; Sjödin et al., 2023). Additionally, digital servitization facilitates the creation of new service-oriented revenue models, like subscription services and outcome-based pricing, through the use of digital tools and smart systems (González Chávez, Despeisse, et al., 2023; GÜR, 2023). These innovations not only reduce production costs but also contribute to environmental sustainability.

Beyond financial benefits, digital servitization plays a critical role in social and environmental sustainability. It promotes integrated value chain collaboration through IoT and Industry 4.0 technologies, enabling seamless interactions and collaborative maintenance strategies that reduce inefficiencies and promote circular economy practices (Alcayaga & Hansen, 2024; Kim et al., 2023). Shared platforms and cross-industry partnerships build resilient ecosystems, fostering the co-creation of value and addressing sustainability goals (Chen et al., 2023; Kolagar et al., 2024). Digital servitization socially democratizes access to critical services and technology, thereby increasing social inclusion and creating opportunities for workforce skill development and workplace safety (Bressanelli et al., 2024; Chang et al., 2024; González Chávez, Despeisse et al., 2023; González Chávez, Unamuno, et al., 2023; Kim et al., 2022; Opazo-Basáez et al., 2018). By enhancing stakeholder collaboration through gamification and technology integration, firms can achieve improved sustainable performance and co-created value (Behl et al., 2024; Liu et al., 2020).

Environmentally, digital servitization enhances energy efficiency, optimizes resource use, and supports recycling and waste management. IoT, AI, and data analytics enhance energy utilization and reduce waste, with lifecycle assessments showing significant reductions in energy consumption and emissions (Jankovic-Zugic et al., 2023; Kruschke et al., 2023). Smart technologies and circular business models optimize resource use and reduce material wastage, aligning with circular economy strategies (Kim et al., 2022; Li et al., 2021). IoT-based tracking and smart packaging optimize the recycling processes and reduce food waste, ensuring that recyclable materials feed back into the production processes (Kabadurmus et al., 2023; Zheng et al., 2020). Integrating digital technologies into lifecycle processes enables firms to exploit reuse, remanufacturing, and recycling opportunities more effectively to reduce waste and enhance sustainability (Alcayaga & Hansen, 2024; Bressanelli et al., 2024). Digital servitization, through its multi-dimensional support for economic, social and environmental sustainability, represents an all-around key enabler for attaining sustainable development (see Figure 4).

Figure 4. Digital Servitization Driving Sustainability



Sustainable digital servitization has emerged as an important research subject due to the increased rate of digital transformation and calls for sustainable development across the globe. Most of the articles included in this study were published in 2023 and 2024, reflecting the recent surge of interest and research activity in the intersection of digital servitization and sustainability. These studies show that the methodological landscape is diverse.

Out of 52 studies, 19 used quantitative research methods utilizing structured approaches like surveys and statistical analyses to measure firms' performance, operational efficiency and sustainability outcomes. This method is relatively efficient in data collection and analysis, mainly when using tools such as surveys and experiments, as it allows researchers to collect large amounts of data relatively quickly (Zyphur & Pierides, 2020).

Furthermore, it often involves large sample sizes, which can increase the generalizability of the findings to a broader population. For instance, Upadhayay et al. (2024) examined the effects of digital and green servitization using the Propensity Score Matching (PSM) approach based on data from 42,000 firms across 38 global economies. This allows researchers to draw broader conclusions and predict the phenomenon under study. Only two of these quantitative studies adopted the case study method to provide deeper insights.

Qualitative approaches were represented by 9 papers, which represent in-depth approaches such as single and multiple case studies. Of the 9 qualitative studies, 4 used multiple case study designs, 4 used single case study methodologies, and 1 study used interviews-based framework (see Table 2). This underlines the exploratory nature of the field, with a strong emphasis on context-specific insights into digital servitization and sustainability practices. However, these approaches' tendency to lack theoretical generalization or replication across diverse contexts is a limitation.

Table 2. Methodological Characteristics of the Sample

Type of Paper	Number of Papers	Characteristics
Quantitative	19	2 case studies
Qualitative	9	4 multiple case studies, 4 single case studies, 1 interviews-based framework study
Mixed Method	9	-
Conceptual	5	-
Literature Review	10	-

Of these, nine studies used mixed-method approaches, which blend qualitative and quantitative techniques. In such cases, the depth of qualitative inquiry is well-balanced with the generalizability of quantitative findings. Five conceptual papers were purely theoretical, with no empirical validation. Literature reviews featured in 10 papers, synthesizing existing research to identify trends, gaps, and theoretical improvements. Advanced computational techniques, such as bibliometric analyses and text mining, were also characteristic, providing valuable insights by managing large datasets and conducting analyses.

Some analytical techniques applied in the selected studies were thematic coding and grounded theory for qualitative data. In contrast, for quantitative data, some of the chosen analysis methods were structural equation modeling (Lee et al., 2021; Mihardjo et al., 2020; Pham & Vu, 2022), econometric analysis (Xie et al., 2023), and simulation-based analysis (Bressanelli et al., 2024; Kim et al., 2022; Kumar Jena & Singhal, 2023). All of these prove helpful, however each method has its limitations.

Moreover, there has been a lack of longitudinal studies, which can be explained by the fact that digital servitization and sustainability are still emerging. As research in this area matures, we might see more longitudinal studies specifically designed to track the long-term impacts of digital servitization on sustainability.

The industries most frequently studied include manufacturing, electronics, automotive, and maritime shipping, reflecting their early adoption of digital servitization practices. In contrast, research on healthcare, renewable energy, and biomanufacturing is limited. The research is geographically concentrated in Europe, East Asia, and North America, with minimal focus on developing economies. This geographic and sectoral bias highlights a critical gap in understanding the global applicability of sustainable digital servitization frameworks.

Summarizing, the emerging field of sustainable digital servitization demonstrates a diverse methodological landscape, reflecting its exploratory nature and growing importance in academia and industry. However, the lack of longitudinal studies, geographic diversity, and coverage of underrepresented industries highlight significant gaps that future research must address to enhance sustainable digital servitization frameworks' global relevance and applicability. The next chapter will discuss the suggestions for future research and this study's theoretical and managerial implications and limitations.

5 Conclusion

This section provides a detailed overview of the study's implications and areas for future exploration. First, it identifies key opportunities for further research to deepen the understanding of digital servitization's role in sustainability. Next, it highlights the theoretical contributions made by an integrative framework, offering new perspectives on the relationships between antecedents, processes, and outcomes of sustainable digital servitization. The managerial implications underscore practical strategies for organizations to adopt sustainable digital servitization practices effectively. Finally, the limitations of this study are discussed, acknowledging constraints in methodology and scope.

5.1 Future Research Opportunities

This section offers a roadmap for future research in sustainable digital servitization. While the field has significantly grown, several underexplored areas present valuable opportunities for scholarly inquiry. The Linkage-Exploration Review Matrix (See Figure 2) points out several underrepresented linkages, which indicate areas where fewer or no studies have been identified. These gaps in the matrix provide opportunities for future research to focus on the critical intersection of antecedents, processes, and outcomes of sustainable digital servitization.

There is limited research on customer involvement in driving sustainability and circular practices (e.g., product reuse, recycling, and lifecycle optimization). For successful sustainable digital servitization transformations, there is a need to understand further the impact of customer-driven feedback loops or behaviours that might affect circular strategies. Limited studies address how real-time customer feedback from digital platforms influences sustainable business model design and transformation. Customer involvement in co-creating solutions tailored to specific needs could lead to models that enhance customer satisfaction while reducing resource waste.

There is also a need to understand the role of customer-driven feedback in shaping sustainable digital supply chains through co-creation or demand-driven innovations. Most studies emphasize economic and environmental sustainability outcomes, with minimal attention paid to social sustainability dimensions such as workforce development and equitable access to digital servitization benefits.

Few studies explore how external markets or regulatory pressures shape sustainable business model innovation. Market conditions like competition, regulatory compliance, and environmental trends are critical for driving innovation. Research could illuminate how firms adapt their business models to these external pressures.

Future research can focus on integrating digital technologies like Artificial Intelligence (AI) to optimize supply chain processes and enhance sustainable and efficient operations. Several studies discuss the technological elements, but the direct integration of advanced technologies in developing innovative business models has not been discussed extensively. For example, future research can explore how IoT-enabled data collection or AI-driven analytics transform service-oriented business models to align with sustainability goals.

Geographically, there is a need to address the current bias by studying the applicability of sustainable digital servitization in developing economies and resource-constrained settings, such as Africa, South Asia, and South America, while identifying barriers and enablers specific to these regions. Future research could focus on the potential of cross-industry collaboration, mainly on ecosystem synergies between distinct sectors such as manufacturing, logistics, and energy, by exploring the development and implementation of shared digital platforms that facilitate collaboration and drive sustainability across these sectors.

Longitudinal studies should be conducted to assess the long-term sustainability impacts of digital servitization and to track and analyze the changes in key performance indicators such as operational efficiency, environmental benefits, and social outcomes over time.

5.2 Theoretical Contribution

This study makes a significant theoretical contribution to the field of digital servitization by advancing the understanding of its role as an enabler of environmental, social, and economic sustainability. The research addresses the critical gaps in the existing literature by synthesizing insights from 52 systematically reviewed articles and structuring them into an integrative framework. Specifically, it establishes a comprehensive link between antecedents, processes, and outcomes, demonstrating how digital servitization transforms traditional business models into sustainability-oriented service systems.

A proposed framework stands out by categorizing the antecedents of sustainable digital servitization into four distinct categories: Technological, organizational, strategic, customer-centric, and market environmental elements. These elements support transitioning from the product-driven to the digitally enabled service-oriented model of sustainability. Moreover, the paper integrates the antecedents with core processes, business model innovation, technology integration and circular economy strategies to provide a holistic view of how such interrelated ingredients lead to sustainability. Unlike previous studies, this paper highlights the intertwined role of these components to strengthen the explanatory power of sustainable digital servitization frameworks.

Digital servitization's operational and technological aspects have been explored by prior studies (Kohtamäki et al., 2021; Reim et al., 2015), but this study advances the sustainability conversation through a triple-bottom-line perspective. The framework is aligned with the global sustainability objectives by focusing on the tangible environmental benefits (e.g., waste reduction and energy optimization), social outcomes (e.g., skill development) and economic gains (e.g., resource optimization and revenue growth). However, the scope of sustainability outcomes is expanded by including emergent themes like stakeholder collaboration and customer co-creation. This study follows the processual research methodology of Pettigrew (1997) for identifying drivers of sustainable digital servitization and mapping the routes whereby these drivers lead to outcomes. This methodological thoroughness enhances current literature on digital servitization by (i) highlighting the dynamic interrelationships among the antecedents, processes and their impacts on sustainability and (ii) positioning the theory within the overall theory of digital servitization and sustainability. For example, the analysis shows that technological advances like AI and IoT accelerate the implementation of circular business model innovations, while organizational capability and customer orientation intensify this effect.

This work also provides a springboard for future research of underexplored areas: the role of emerging technologies in creating social sustainability and the contextual factors shaping the deployment of digital servitization strategies in different industries.

5.3 Managerial Implications

This study provides actionable insights for managers seeking to integrate digital servitization with sustainability-driven objectives. The findings highlight the crucial role of digital skills and capabilities in navigating the complexities of transitioning from product-centric to service-oriented business models, offering the roadmap for aligning organizational strategies with broader environmental, economic, and social goals.

One key implication is the need for managers to prioritize investments in digital infrastructure and technologies like IoT, AI, and blockchain. These tools enable operational efficiency and serve as foundational enablers of sustainability outcomes. For example, IoT-enabled predictive maintenance can extend product lifecycles and reduce waste, while AI-driven analytics can optimize resource use and energy consumption. Managers must ensure their organizations possess the technical capacity and expertise to implement these technologies effectively while fostering a culture of digital literacy across teams.

Additionally, this study emphasizes the importance of rethinking business models to incorporate sustainability at their core. Service-oriented approaches such as pay-per-use and outcome-based models must be investigated at the managerial level to serve evolving customer expectations and promote the principles of the circular economy. These models are resource-efficient and low on environmental impact; they create value for businesses and society. Such models must be established by concerted cross-functional effort in which marketing, operations, and IT teams forge one cohesive team to design and deliver enhanced value-added services.

The second takeaway is that sustainable digital servitization requires customer-centricity. It is possible to create satisfaction and loyalty by engaging customers as active participants in co-creation processes such as feedback loops and personalised offerings. To rank among the future stars, managers must utilize digital platforms to gather and analyse customer data and ensure service innovation aligns with the needs of consumers and sustainability preferences. Organizations can differentiate their offerings based on the markets that are environmentally conscious by doing so.

Collaboration within digital ecosystems also emerges as another strategic imperative. Managers are encouraged to cultivate strong partnerships with the stakeholders, including suppliers, customers, and regulators, to facilitate resource sharing, knowledge exchange, and innovation. Digital ecosystems that prioritize sustainability through transparent supply chain practices and shared accountability can drive collective progress toward achieving sustainability goals. Establishing such partnerships may involve overcoming data interoperability and trust challenges, underlining a need for robust governance structures.

Lastly, the research highlights the significance of embedding sustainability into organizational strategy and decision-making processes. Managers should adopt metrics and performance indicators that reflect environmental and social impacts and economic outcomes. Sustainability should not be treated as a peripheral concern but as an integral component of value creation. This shift requires a long-term vision and the commitment to balancing short-term profitability with long-term sustainability goals.

5.4 Limitations of the study

Though contributing to literature, this systematic literature review (SLR) has built-in limitations that should be addressed to contextualize its findings and guide future research. These methodological limitations result from the data's scope and some conceptual problems intrinsic to systematic reviews.

Though rigorous, this is the first criticism of review methodology, dependent upon solely secondary data sourced from the ‘academic’ sphere of discourse. The Gray literature and industry reports, which offer more nuanced and practical insights into the complex DNA of digital servitization and sustainability, are excluded.

The second way this scope is influenced is due to its selection criteria, which put a select few high-impact journal publications first. However, this means that academic details can be ensured, at the expense of innovation and the experimental, when studies of niche or emerging are intended. This is especially problematic in fields undergoing rapid change like digital servitization, where novel technologies and frameworks like blockchain and AI are often introduced but have yet to appear in top-tier journals. Additionally, a few articles were eliminated as they illustrate a modest piece unrelative of the stage of sustainable digital servitization.

Further, the literature included is time-limited. The review may or may not keep up with innovation as fast as it is entering the world of digital technology, particularly areas where AI is blended into sustainability metrics or blockchain is deployed for circular economy initiatives.

However, although this review explicates the crux of the conceptual relationships among the antecedents, processes, and outcomes literature, it does not specify the quantitative metrics and industry benchmarks for quantifying the extent of the sustainability influence of digital servitization. While this is valuable in its contribution to theoretical development, it impedes the capacity to assess the actual empirical benefits of the proposed frameworks.

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Appendices

Appendix 1. Table A1. Studies, Linkages, and Key Findings

Study Code	Author(s)	Type	Sample Size	Sample Characteristics	Linkages	Core Findings	Digital Servitization and Sustainability Focus
01	Alcayaga & Hansen (2024)	Qualitative	27 organizations	-B2B industries transitioning to a circular economy -43 Expert Interviews	B1-B4 B1-B5 B4-B5 B1-B6 B4-B6 B5-B6 B6-C2 B6-C4	-Development of a funnel framework for "smart circular systems" (SCS) integrating IoT, PSS, and circular economy principles. -Identify 20 micro-level activities classified into "smart use," "smart circular," and cross-strategy activities to optimize product life cycles. -Highlighted challenges are inter-organizational collaboration, data standardization, and circular product design.	-Digital servitization reduces waste and extends product lifecycles, enhancing environmental sustainability. -IoT-enabled transparency fosters stakeholder collaboration for better circular practices. -Service models like pay-per-use reduces costs and generates revenue.
02	Arioli et al. (2023)	Qualitative	1	-Italian manufacturing company	A1-B2 A1-B3 B2-B3 B3-B2 B2-B6 B3-B6	- SEEM-Smart methodology supports smart PSS design, balancing customer needs and process efficiency. - A case study in dishwasher manufacturing demonstrates the value of IoT and cloud computing in improving service delivery.	- IoT-enabled remote monitoring reduces waste and extends product life. - Collaboration between manufacturers and distributors improves job satisfaction and reduces errors.

					B6-C3 B6-C4		
03	Bag et al. (2024)	Quantitative	202 firms	-Surveys 202 manufacturers actively involved in Industry 4.0	A1-B* B6-C1 B6-C4	- Identification of three foundational capabilities for developing SCPS smart circular product-service systems: product lifetime database creation, analytics and business intelligence, and actuating capabilities. - SCPS enhance financial and environmental performance in volatile business environments.	-SCPS optimize resource use and waste reduction through data-driven remanufacturing and recycling practices. - SCPC positively impacts financial performance by reducing operational costs through closed-looped processes.
04	Behl et al. (2024)	Quantitative	254	-254 questionnaire to the firms in the retail industry	B4-C1 B6-C2 B6-C3	- Gamification positively impacts goal commitment (GC) and green supply chain management practices (GSCMP). -Both GC and GSCMP positively influence sustainable performance (economic, environmental, and social). -Gamification enhances the relationship between DS and GC, although it does not significantly moderate the effect of DS on GSCMP.	- Digital servitization (DS) and gamification synergistically drive sustainability by enhancing GSCMP and fostering engagement through GE. - Digital servitization (DS) is vital in achieving triple-bottom-line sustainability goals and connecting technology adoption with environmental and social improvements.

						-Larger firms are more likely to benefit from GSCMP, but firm age does not significantly affect sustainable performance.	
05	Bressanelli et al. (2024)	Quantitative	-	-Hypothetical scenario based on real-world cases	B1-B3 B3-B1 B1-B6 B3-B6 B6-C1 B6-C3 B6-C4	-Development of a what-if simulation model: digital servitization-based circular economy (CE) scenarios can lead to win-win-win outcomes, enhancing environmental (reduction in CO_2 emissions), economic (higher supply chain profits), and social (increased employment opportunities) sustainability. -Key strategies include product life extension, pay-per-use models, and product reuse, supported by digital technologies and maintenance services.	-Digital servitization enables sustainability by integrating digital tools into CE business models, reducing waste, and promoting resource efficiency. -It showcases triple-bottom-line benefits through environmental impact reduction, economic gains for stakeholders, and enhanced social value via job creation.
06	Bu et al. (2021)	Mixed Method	30 participants	-Elderly population using VR-based smart products	A1-B2 A1-B3 A3-B2 A3-B3 B2-B3 B3-B2 B2-B6	-The proposed user-centric framework integrates VR technology for the value-added design of smart product-service systems (PSS), combining user-generated and system-generated data for enhanced user experience.	-Smart product-service systems leverage digital tools (e.g., VR) to foster sustainability through extended product lifecycle and enhanced user engagement. - A data-driven and user-centric approach contributes to the broader understanding of digital servitization's role in achieving

					B3-B6 B6-C3 B6-C4	-Objective evaluation methods using brain activity data (fNIRS) confirmed the system's effectiveness in enhancing user satisfaction and meeting sustainable product lifecycle needs.	sustainability goals such as resource optimization and value co-creation.
07	C. H. Kim et al. (2022)	Qualitative/ Literature Review	119 publications	-Review of EEE sector literature	A1-B* A1-B1 A2-B1 B1-B6 B6-C1 B6-C3 B6-C4	-Circular Economy Business Models (CEBMs) in Singapore and South Korea's Electrical and Electronic Equipment (EEE) sector are shaped by local contexts. -While Singapore emphasizes result-oriented models and government collaborations, South Korea adopts rental and leasing strategies enabled by advanced digital technologies, showcasing diverse pathways to achieving circularity and sustainability.	-Digital technologies like IoT, cloud computing, and big data analytics are pivotal in driving servitized solutions by enabling smarter, more efficient, and customer-focused offerings. -CEBMs deliver various environmental, economic, and social benefits.
08	C. Z. Li et al. (2021)	Mixed Method	1	-Prefabricated housing company in China	A1-B4 A1-B5 B4-B5 B5-B4 B4-B6 B5-B6 B6-C1	-Development of an intelligent platform (SPSS) by integrating advanced technologies such as blockchain, IoT, CPS, and BIM. -SPSS improves sustainability by addressing inefficiencies, fragmented management, and supply chain challenges through real-time	- SPSS combines products and services with advanced digital technologies like IoT, BIM, and blockchain and addresses Triple-bottom-line sustainability: reducing environmental impacts, enhancing economic returns, and fostering collaborative ecosystems.

					B6-C2 B6-C3 B6-C4	monitoring, data sharing, and value co-creation.	
09	Chang et al. (2024)	Mixed Method	7	-14 interviews from manufacturing companies	A3-B3 B3-B6 B6-C1 B6-C3 B6-C4	-Three categories of smart product-service systems (PSS) are explored to demonstrate how customization enables sustainable value creation: product-oriented, use-oriented, and result-oriented. - Digital technologies such as IoT, AI, and big data enable customization, leading to extended product life cycles, improved resource efficiency, and reduced environmental impact.	-Digital servitization supports sustainability through customized smart PSS. -Customized PSS models promote resource reuse, waste reduction, and lifecycle extension, closely aligning with circular economy goals.
10	Chen et al. (2023)	Quantitative	1083	-Listed firms in digital servitization	A1-B* A2-B* A4-B* B6-C4	-Digital servitization (DS) and digital infrastructure contribute to sustainable development in digital ecosystems focusing on financial and environmental performance. - Firms that excel in environmental practices gain more from digital servitization and foster a financial growth and adoption cycle.	-Digital servitization and infrastructure drive sustainability in digital ecosystems, enhancing financial and environmental performance through service innovation and resource optimization.

						- Public-supported digital infrastructure further magnifies these potential benefits, mainly for environmentally advanced firms.	
11	De La Calle et al. (2021)	Mixed Method	4	-Capital goods companies	B1-B3 B1-B4 B1-B6 B3-B1 B3-B4 B3-B6 B4-B1 B4-B3 B4-B6 B6-C3	-Digital product–service innovation (PSI) integrates servitization and sustainability, showing a notable environmental and economic impact but limited to social benefits. -Advanced services, such as predictive maintenance or data-driven consulting, excel in sustainability through resource efficiency, lifecycle extension, and revenue growth. -Supply chain integration (SCI) is critical, with an advanced service requiring deeper customer and supplier collaboration than an essential service.	- Digital PSI or Digital servitization fosters sustainability, highlighting lifecycle management, resource optimization, and collaboration. -Economic and environmental dimensions of sustainability are thoroughly addressed as digital PSI that improves a firm's performance while contributing to green practices. -Social sustainability remains underexplored but shows the possibility for job creation and enhanced safety.
12	González Chávez et al. (2024)	Qualitative	13 companies	-13 Interviews from maritime shipping firms	A4-B* B3-B6 B6-C3 B6-C4	-Digital servitization is the transformative strategy in a maritime shipping industry that enhances sustainability through lifecycle management, predictive maintenance, and service-based models.	-Digital servitization drives sustainability by promoting resource efficiency, reducing emissions, and enabling circular practices in the maritime sector.

						-Regulatory pressures drive innovation and prompt firms to adopt greener technologies and digital tools like IoT and AI. - Barriers to adoption include data silos, limited connectivity, and workforce skill gaps; however, opportunities lie in collaboration and standardization across stakeholders.	- Economic benefits include cost savings and revenue from the servitized business models. Environmental benefits focus on reducing emissions and resource optimization, while workforce development offers potential for social sustainability through upskilling initiatives.
13	González Chávez, Despeisse, et al. (2023)	Mixed method		-Multiple research projects	A2-B1 A4-B1 B1-B6 B6-C1 B6-C3 B6-C4	-Development of a framework (SaaS) with four dimensions integrating digital servitization with sustainability and positioning sustainability as the core value of service offerings. -The SaaS paradigm emphasizes lifecycle data sharing, value co-creation, and cross-disciplinary collaboration to achieve circular economy principles. -Empirical case studies highlight the role of digital technologies like IoT, AI, and automation in enabling resource optimization, transparency, and stakeholder engagement.	-Digital servitization enables sustainability through the SaaS paradigm, advancing circularity and resource efficiency. -It is essential to embed sustainability into all lifecycle stages, contributing to economic, environmental, and social outcomes via servitized business models.

14	González Chávez, Unamuno, et al. (2023)	Qualitative	3 firms	-Machine tool manufacturers	A1-B2 A2-B2 B2-B6 B6-C3	- Digital servitization in the machine tool industry integrates digital tools like IoT and simulation to optimize manufacturing processes, reduce waste, and extend equipment lifecycles. -Risks linked with digital servitization include data integration, interoperability, and stakeholder alignment challenges, highlighting a need for contingency plans and collaboration. -Digital services, such as Zero Defect Manufacturing (ZDM), First Time Right (FTR), and Lean Production (LP), illustrate servitization-driven sustainability through resource efficiency and improved production flows.	-Digital servitization leverages IoT, data analytics, and simulation tools to optimize manufacturing processes, reduce defects, and improve resource utilization, addressing triple-bottom-line Sustainability.
15	GÜR (2023)	Qualitative/ Literature Review	27 articles	-Fashion industry applications	B3-B5 B3-B6 B5-B3 B5-B6 B6-C1 B6-C4	- Smart Product-Service Systems (Smart PSS) in the fashion industry integrate digital technologies like the Internet of Things (IoT), RFID, and AI to enhance resource efficiency, prolong product lifecycles, and promote circular practices.	- Smart Product-Service Systems (Smart PSS) enable sustainability in the fashion sector through lifecycle optimization, waste reduction, and circular economy models.

						-Servitization challenges traditional "fast fashion" models by introducing repair, reuse, and co-creation services, reducing waste and the environmental impact. -Obstacles like consumer behaviour, cost complexities, and infrastructure gaps, but digital customization and real-time demand production offer a remarkable opportunity for sustainability.	
16	Halstenberg et al. (2021)	Mixed Method	1	-Engineering teams	B5-B6 B6-C1 B6-C3 B6-C4	-Develop a knowledge transfer system to integrate Circular Economy (CE) strategies into the early design phases of Smart-Circular Product-Service Systems (Smart-Circular PSS), leveraging Model-Based Systems Engineering (MBSE). - The Smart-Circular PSS Lifecycle Flowchart (SCPLF) and service archetypes guide teams in selecting and implementing CE strategies like repair, reuse, and remanufacturing. -The system's application in designing a sustainable streetlight system demonstrates its potential to enhance sustainability by aligning product lifecycles with CE principles.	- Smart-Circular PSS enable sustainability by embedding CE strategies into the design process. -Lifecycle-based optimization and collaborative engineering are critical to achieving environmental, economic, and social sustainability.

17	Jankovic-Zugic et al. (2023)	Quantitative	10 firms	-Automotive supply chains	B4-B6 B6-C1 B6-C2 B6-C3 B6-C4	-Integrating digital technologies (e.g., IoT, AI, cloud computing) and product-related services (e.g., maintenance, leasing) enhance collaboration between manufacturers and suppliers, known as Servitization 4.0 in the automotive supply chain. -It improved supply chain resilience and sustainability, particularly during disruptions like COVID-19.	- Servitization 4.0 enables the integration of Industry 4.0 technologies and Circular Economy principles, reducing waste and optimizing resources.
18	Kabadurmus et al. (2023)	Quantitative	1	-Grocery store	A1-B2 A3-B2 A4-B2 B2-B6 B6-C1 B6-C3 B6-C4	This study proposes a data-driven decision support system integrated with smart packaging to manage perishable grocery supply chains during outbreaks like COVID-19, ensuring hygiene, quality, and sustainability. -Smart packaging, part of a Smart Product-Service System (Smart PSS), enables dynamic pricing based on freshness, significantly reducing food waste, improving inventory turnover, and maximizing profits. -Experimental results highlight critical factors optimising grocery store	-Digital servitization through smart PSS fosters sustainability in supply chains via waste reduction, resource efficiency, and enhanced profitability. Integrating IoT and smart labelling technologies demonstrates their potential to address economic, environmental, and social sustainability.

						performance, such as stock capacities, freshness periods, and quantity discounts.	
19	Kolagar (2024)	Qualitative	7 firms	-23 interviews from transportation and logistics ecosystem actors	A2-B1 A2-B4 B1-B4 B1-B6 B4-B1 B4-B6 B6-C2 B6-C3 B6-C4	-Development of a multi-level framework for ecosystem orchestration that contains individual, organizational, and ecosystem levels. This framework facilitates the co-creation of data-driven digital services to enhance sustainable industrial outcomes. -Digital technologies like IoT, AI, and cloud computing facilitate the transition from product-centric models to sustainability-oriented ecosystems. Ecosystem orchestration ensures alignment among diverse actors, achieving environmental, economic, and social benefits through improved collaboration and resource utilization.	- Digital technologies like IoT, AI, and cloud computing enable the shift from product-centric models to sustainability-focused ecosystems. - Ecosystem orchestration creates a win-win situation by fostering collaboration among diverse stakeholders. More efficient resource management leads to environmental, economic, and social improvements.
20	Kolagar et al. (2024)	Mixed Method	180 firms	-Swedish manufacturing companies	A1-B1 B1-B4 B1-B6 B4-B1 B4-B6	-Identification of five smart solution strategies that empower manufacturers to realize sustainable performance for their customers.	- Smart solutions enabled by digital servitization drive sustainability performance through AI, collaborative ecosystems, and customized service models.

					B6-C1 B6-C2 B6-C3 B6-C4	- It emphasizes the role of digital technologies and co-created solutions in reducing waste, optimizing resources, and improving economic, environmental, and social outcomes. -The configurational approach highlights multiple pathways (e.g., equifinality and causal complexity) to achieve sustainable performance, reinforcing the need for flexible and collaborative strategies.	- Outcome orientation and ecosystem orchestration help to align digital servitization with sustainability objectives.
21	Kruschke et al. (2023)	Qualitative/ Literature Review	27 papers	-Research articles on LCA, MBSE, and circular PSS	B2-B6	-This SLR highlights that the ecological dimension of smart-circular PSS is still in the conceptualization stage. A proactive approach to quantifying ecological impacts during early development is rare. -Circularity is not fully considered, and many studies do not use Cradle-to-Cradle system boundaries or fully implement the 9R strategies (which include approaches like recycling, remanufacturing, and reusing).	-There is a critical need for a more integrated and data-driven approach to developing sustainable PSS that aligns perfectly with the goals of digital servitization, which aims to leverage digital technologies to create more sustainable and customer-centric value propositions.

22	Kumar & Sharma (2023)	Mixed Method	421 articles	-SMEs in Industry 4.0 contexts	A1-B* B6-C1 B6-C3	-While adopting Industry 4.0 in SMEs, several barriers have been identified, such as resource constraints, workforce skills gaps, and lack of digital strategies. -IoT, AI, and dynamic capabilities are enablers of sustainability.	Digital technologies such as IoT and AI promote sustainability in SMEs through waste reduction, resource optimization, and lifecycle approaches.
23	Kumar Jena & Singhal (2023)	Quantitative	2	-Hypothetical supply chain scenarios	A2-B1 A2-B4 B1-B4 B1-B6 B4-B1 B4-B6	-Integrated systems maximize environmental and economic benefits, while Vertical Nash models yield the highest total profit due to optimal digitalization and sustainability efforts. -Green innovation (e.g., green delivery, recyclable products) and CSR investments attract environmentally conscious customers and boost competitive advantage.	-Digital servitization, combined with sustainability and CSR, drives triple-bottom-line sustainability (economic, environmental, social).
24	Lee et al. (2024)	Quantitative	482 firms	-Korean firms adopting PSS (varied industries)	A2-B5 B5-B6 B6-C1 B6-C4	-Absorptive and transformative capacities for firms enable the assimilation of external knowledge and adaptation to digital transformation. -Environmental strategies are pivotal mediators in linking digital servitization with green innovation. They help firms align	Digital servitization drives green innovation by integrating digital technologies like IoT, AI, and big data analytics with Product-Service Systems (PSS). -Environmental strategies act as mediators by associating digital servitization efforts with some green innovation outcomes, like

						sustainability goals with technological and operational changes, leading to eco-friendly product and process innovations. -Digital servitization integrates product-service systems (PSS) with digital tools. For instance, IoT and AI enhance sustainability outcomes, like waste reduction, resource efficiency, and customized services.	adopting renewable energy, developing carbon-neutral processes, and integrating circular economy principles into product designs.
25	Liu et al. (2020)	Quantitative	Case study	-Smart air-conditioning systems	B2-B5 B2-B6 B5-B2 B5-B6 B6-C1 B6-C3 B6-C4	-An integrated evaluation method (RBT: Rough Best Worst Method and TODIM: an acronym in Portuguese for Interactive and Multi-Criteria Decision Making) is proposed to assess the sustainability of the Smart Product-Service Systems (Smart PSS), addressing its complexities in the decision-making under uncertainty. -The effectiveness of RBT is exemplified with the help of a case study on smart air-conditioners in prioritizing solutions that balance cost, performance, and sustainability.	-Smart PSS aligns with the sustainability goals through ICT-enabled lifecycle optimization and decision-making frameworks. It enables IoT-based monitoring and adaptive control systems, optimizing resource consumption and enhancing user experience.

26	M. Kim et al. (2023)	Quantitative/ Literature Review	419 Articles	-Studies on CE, PSS, and Industry 4.0	B5-B6	-10 key research topics in the context of digital servitization and Smart Product-Service Systems (Smart PSS) within Industry 4.0 have been identified. These include enablers like technology integration, digitalization, and capabilities alongside engineering aspects, such as design, business planning, and monitoring. -An enabler–engineering–goal framework is also proposed, showing how Industry 4.0 technologies like IoT, AI, and big data enable servitization and Smart PSS development, aligning technology-driven transformations with the sustainability objectives.	-Digital servitization, supported by Industry 4.0 technologies, promotes sustainability by integrating data-driven and lifecycle-based strategies into the servitization practices.
27	Mauersberger et al. (2023)	Qualitative	7 cases	-manufacturers adopting smart PSS	A1-B2 B2-B6 B6-C1 B6-C4	-Smart Product-Service Systems (Smart PSS) integrated with digital technologies such as IoT, AI, and cyber-physical systems transform manufacturing practices. -Business models, design principles, quality aspects, and sustainability dimensions of Smart PSS have been highlighted, emphasizing modularity, value co-creation, and context-aware systems.	-Digital servitization through Smart PSS enhances manufacturing sustainability. - Key insights include the role of modularity, lifecycle optimization, and advanced digital technologies in achieving triple-bottom-line sustainability and fostering circular economy practices.

						-Sustainability in Smart PSS focuses on extending product lifecycles, circular economy strategies, and balancing economic, environmental, and social impacts during the design and operation phases.	
28	Mihardjo et al. (2020)	Quantitative	195 firms	-UAE-based digital service firms	A2-B* B6-C1	-Green Information Systems (GIS) enhance organizational agility (OA) and customer experience (CX) to foster digital service innovation (DSI) and achieve sustainable performance (SP) in the ICT sector. -GIS enables resource efficiency and eco-friendly practices, aligning digital transformation models with sustainability goals. -The Indonesian ICT sector results confirm the critical role of OA and CX in driving DSI and SP, with GIS accelerating this impact.	-Digital servitization, driven by GIS, supports sustainability through enhanced resource efficiency, customer-centric digital innovation, and lifecycle optimization. -GIS demonstrates that technology can transform digital service ecosystems into sustainability-oriented models
29	Münch et al. (2022)	Qualitative	4 firms	-18 Interviews from large-scale manufacturers	B3-B6	-46 key capabilities across dimensions like people, culture, goals, processes, technology, and infrastructure have been identified, using a socio-technical systems	-Digital servitization requires aligning human capabilities with technological advancements to create adaptive and resilient ecosystems.

						framework to explore digital servitization capabilities. -Smart Product-Service Systems (Smart PSS) and Industry 4.0 goals are achieved due to an interplay between human, technological, and environmental components.	-Customer-centric design, real-time data use, stakeholder collaboration, and lifecycle optimization enhance sustainability.
30	Nicoletti & Appolloni (2023)	Qualitative/ Conceptual	10 experts	-Servitization contracts in manufacturing	A1-B1 B1-B6	- AI can propel Servitization 5.0 by prioritizing human-centricity, sustainability, and resilience within the context of Industry 5.0. --Key areas of exploration include the role of AI in enabling XaaS(Everything-as-a-Service) models, optimizing lifecycle management, enhancing predictive maintenance, and ultimately, delivering more excellent value to customers. - AI enhances circular economy practices, social innovation, and real-time decision-making in servitization ecosystems, addressing sustainability's economic, environmental, and social dimensions.	-Digital servitization powered by AI supports sustainability goals, including waste reduction, resource efficiency, and stakeholder collaboration. - A comprehensive framework is provided for integrating AI to achieve triple-bottom-line sustainability within servitization, serving as a crucial guide for exploring and implementing sustainability-enabling technologies.
31	Opazo-Basáez et al. (2018)	Quantitative	228 firms	-Automotive companies	B2-B5 B2-B6	- Digital servitization (integration of digital technologies) and green servitization	- Digital Servitization is a prerequisite for green servitization as it provides the

					B5-B2 B5-B6 B6-C1 B6-C3 B6-C4	(sustainability-focused services) affect firm productivity in the automotive industry. -A dual-servitization strategy (digital and green services) is identified as critical for achieving productivity gains, with digital servitization serving as a prerequisite for green servitization to enhance environmental and economic performance. - A 33.4% productivity increase is observed for firms adopting both strategies simultaneously.	infrastructure (e.g., IoT, AI, data analytics) to monitor and optimize resource use, emissions, and lifecycle management. - Dual strategies contribute to cost savings, increased customer satisfaction, and new revenue streams through service-based models like subscriptions and fleet management. - Green servitization reduces emissions, minimizes waste, and aligns with circular economy principles by extending product lifecycles and enabling recycling/remanufacturing.
32	Paiola et al. (2021)	Qualitative	4	-Small-medium manufacturing firms	A1-B* A2-B*	-Digital servitization driven by IoT-enabled business model innovation (BMI) and networking can lead to sustainability in manufacturing firms. - Dyadic and network configurations are crucial in leveraging digital technologies to improve energy efficiency, reduce waste, and achieve sustainable outcomes. - Manufacturers can incorporate customer-centric and resource-efficient practices into	-Digitally-enabled sustainable servitization supports its goals through innovative BMIs emphasising circular economy principles and lifecycle management. - Networking and collaborative ecosystems enable resource efficiency, waste reduction, and co-created sustainable solutions. It shows the interplay of technology and collaboration in achieving sustainability goals.

						their value propositions using IoT-driven servitization to achieve sustainability outcomes.	
33	Pan et al. (2019)	Qualitative	-	-Logistics networks	B1-B4 B1-B6 B4-B1 B4-B6 B6-C2	- Smart Product-Service Systems (Smart PSS) improve intelligent interoperable logistics by embracing the Physical Internet (PI) concept. This facilitates resource sharing, modularity, and optimised product lifecycle. -BMIs like Logistics-as-a-Service (LaaS) and plug-and-play systems align logistics operations with sustainability goals to promote efficiency, adaptability, and resource optimization. - To create a sustainable ecosystem, it is suggested to develop open standards and protocols to ensure seamless interoperability, invest in digital skills training for logistics professionals, and strengthen collaborations among logistics providers, manufacturers, and policymakers	-Digital servitization through Smart PSS and PI boosts logistics sustainability. - Combining IoT, AI, and modular systems supports circular economy principles by minimizing waste and maximizing resource utilization. -Innovations like plug-and-play systems and LaaS emphasize economic, environmental, and social sustainability dimensions.

34	Pham & Vu (2022)	Quantitative	412	-Public service organizations	(None)	- Digital Servitization (DS) facilitates Sustainability-Oriented Organizational Performance (SOOP) through the establishment of Sustainable and Smart Service Innovation Ecosystems (SSSIEs). -Digital Leadership (DL) moderates DS, SSSIE, and SOOP relationships, enhancing their effectiveness. -DS directly improves SOOP by leveraging digital technologies for resource efficiency, collaboration, and lifecycle optimization within public service organizations.	-Digital servitization drives sustainability by integrating collaborative ecosystems and adaptive leadership. - DS reduces operational costs and creates new revenue streams through subscription models, data-driven insights, and lifecycle services.
35	Pirola et al. (2020)	Qualitative/ Literature Review	413 papers	-Research articles on smart PSS	B3-B5 B3-B6 B5-B3 B5-B6 B6-C3	-Five main research streams are identified within Smart Product-Service Systems (Smart PSS): PSS design, digital servitization, decision-making tools, lifecycle knowledge management, and sustainable business models. -Digital technologies, including IoT, cloud computing, and data analytics, transform PSS into smart, sustainable solutions, improving efficiency and stakeholder collaboration.	-Digital technologies, including IoT, cloud computing, and data analytics, transform PSS into smart, sustainable solutions, improving efficiency and stakeholder collaboration. -Circular economy principles are embedded in Smart PSS through modular upgrades, product reuse, and end-of-life recovery strategies. -Lifecycle knowledge management ensures environmental and economic sustainability

						- This study proposes a research agenda addressing integrating digital technologies with PSS for sustainability.	by reducing material waste and extending product lifespans.
36	R. Menon et al. (2024)	Qualitative/ Literature Review	120 papers	-Studies on environmental and economic impacts of servitization	A1-B1 A1-B6 A2-B1 A2-B6 B1-B5 B1-B6 B5-B1 B5-B6 B6-C1 B6-C3 B6-C4	-The triple nexus of servitization, environmental performance, and economic performance has been examined in this SLR by consolidating evidence from over 120 research papers. -It highlights how servitization integrates circular economy principles, reduces emissions, and enhances resource efficiency while fostering long-term revenue streams through innovative business models. -A framework of moderating and mediating variables, such as digitalization, firm culture, and stakeholder management, affecting servitization outcomes is proposed.	-The link between digital servitization and sustainability is examined, highlighting the economic and environmental advantages of servitized business models. -The role of digital technologies and lifecycle management in achieving circularity and fostering sustainable growth is crucial, making it an essential resource for understanding the sustainability potential of digital servitization.
37	Rabetino et al. (2024)	Qualitative/ Literature Review	150 articles	-PSS applications in CE and resource-efficient models	(None)	- Sustainable servitization offers a promising approach to improving resource efficiency and sustainability within supply chains. However, its effectiveness varies depending	- Digital servitization not only aims to enhance operational efficiency but also fosters a broader adoption of sustainable practices in manufacturing by leveraging

						on business models, market dynamics, and technological advancements. - Significant barriers to implementing sustainable servitization include the complexity of integrating and managing product-service systems and the need for substantial changes in business operations. Conversely, technological advancements such as IoT and digital platforms can be powerful enablers by promoting greater efficiency and improved resource management.	advanced technologies and innovative business models.
38	Rakic et al. (2023)	Mixed Method	527 articles	-Literature in digital servitization and Industry 4.0	B1-B6 B6-C3	- This bibliometric analysis identifies several key trends, such as the increasing emphasis on human-centric, sustainable, and resilient services enabled by IoT, AI, and Big Data, with applications in lifecycle management, circular economy, and collaborative ecosystems. The challenges identified are the servitization paradox and low maturity levels among firms adopting Digital PSS.	- sustainability is one of the core new service orientations, reflecting an increasing integration of environmental concerns into digital product-service systems. - The analysis emphasizes the development of services that are not only technologically advanced but also prioritize human-centred approaches and resilience, thereby enhancing both social and environmental sustainability.

39	Ries et al. (2023)	Conceptual	63 publications	-Mechanisms linking smart PSS design to impacts	B3-B5 B3-B6 B5-B3 B5-B6 B6-C3	- Developed a three-step causal logic framework (design, causation, impact) to understand how sustainable smart Product-Service Systems (PSS) create sustainability impacts. -17 mechanisms are grouped into four categories: information, resource, empowerment, and adverse mechanisms, which connect business model properties to sustainability outcomes. -A morphological box toolkit is introduced to help managers design sustainability-driven smart PSS by balancing trade-offs and identifying optimal solutions.	-Digital servitization through smart PSS enables resource efficiency, lifecycle optimization, and customer empowerment, providing actionable insights to achieve triple-bottom-line sustainability. - The connection between digital servitization and circular economy practices is strengthened by integrating lifecycle-based strategies and resource efficiency.
40	Schiavone et al. (2022)	Conceptual	-	-Digitalized manufacturing configurations	A2-B5 B5-B6 B6-C3	-Digital servitization facilitates new configurations in manufacturing systems, significantly enhancing sustainability. -Integrating technological, social, and environmental factors through digital servitization promotes a shift towards more sustainable and efficient manufacturing practices.	- Digital servitization allows for more excellent connectivity between different actors in the manufacturing ecosystem, which improves responsiveness to changes in demand, environmental standards, and social expectations. -By leveraging digital platforms, companies can quickly adapt their manufacturing

						- A conceptual model is proposed to explore how new digital services might reshape manufacturing trajectories to address the urgent challenge of sustainability, emphasizing the role of social and environmental factors when digital transformations in manufacturing occur.	processes and products to meet sustainability goals. - Exaptation, as applied in the digital servitization context, enables manufacturers to repurpose existing technologies for new, unexpected uses that contribute to sustainability.
41	Sjödin et al. (2023)	Qualitative	6	-54 interviews from leading industrial technology firms	A1-B* A1-B1 A2-B1 B1-B6 B6-C1 B6-C4	- AI-enabled Circular Business Model Innovations (CBMI) within digital servitization are conceptualized, with three critical AI capacities – perceptive, predictive, and prescriptive – enhancing resource efficiency and circularity by automating and augmenting decision-making processes. - Successful commercialization of AI-enabled CBMIs centres on dynamic capabilities: value discovery, realization, and optimization, focusing on creating and capturing sustainable value.	- AI's capabilities enable more efficient use of resources, directly contributing to sustainability by minimizing waste and optimizing product life cycles. - AI plays a vital role in fostering innovative business models that integrate sustainability into core business practices, reflecting a shift towards circular economy principles. - By leveraging AI to drive sustainability, firms can develop dynamic capabilities crucial for adapting and thriving in today's rapidly changing business landscape.
42	Song et al. (2021)	Quantitative	1	-Smart washing machine PSS	A1-B*	- A Rough BWM-CRITIC-TOPSIS methodology is introduced to evaluate Smart Product-	- Smart PSS integrates ICT and AI to align with sustainability goals.

						Service System (PSS) designs, integrating subjective and objective weighting techniques while addressing vagueness in decision-making. -Ten economic, environmental, and social criteria for holistic evaluation are also identified. - A case study on smart washing machine PSS designs validates the method, highlighting safety, cost, and reliability as critical evaluation priorities, emphasising triple-bottom-line sustainability.	-Digital tools and methodologies like rough set theory can be applied to evaluate and optimise the sustainability aspects of smart product-service systems -The proposed methodological integration offers a new way to address sustainability in the design and evaluation of smart product-service systems through digital servitisation, emphasising the role of smart technologies in achieving sustainable solutions.
43	Upadhayay et al. (2024)	Quantitative	42,000	-Manufacturing firms across 38 economies	B4-B6 B6-C2 B6-C3	- Digital servitization positively correlates with firms' innovation intensity, as it facilitates resource reconfiguration and integration of advanced technologies like IoT and AI, enhancing adaptability and technological knowledge creation. - Green servitization alone demonstrates a weaker influence on innovation, though its combination with digital servitization results in positive synergies, improving firms’	- Integrating digital and green servitization is a transformative strategy that strengthens resource efficiency and fosters a circular economy. Combining digital tools with green services promotes greater technological innovation, underscoring the importance of integrating sustainable practices with digital strategies.

						innovation outcomes and contributing to sustainability goals. - Public R&D investments significantly amplify the benefits of digital and green servitization on innovation performance, especially in industries like pharmaceuticals, automotive, and electronics.	
44	Vaillant & Lafuente (2024)	Quantitative	213	-Industrial firms in Spain	A1-B2 A2-B2 B2-B6 B6-C3 B6-C4	- Digital servitization significantly enhances firms' environmental and non-financial performance, such as operational efficiency, competitiveness, and customer orientation, compared to non-digital servitization. - Integrating digital technologies in servitization reduces value leakages, facilitates energy efficiency, and improves waste management, especially within manufacturing firms transitioning towards green and circular practices.	- Digital servitization drives environmental performance by optimizing resource utilization, reducing waste, and enabling circular economy practices like lifecycle extension. - Digital servitization enhances operational performance and competitive edge, demonstrating its role in promoting environmental and economic sustainability. - Integrating digital technologies with servitization strategies is essential for unlocking the full potential of both sustainability and performance.
45	Walk et al. (2023)	Quantitative	2 products	-machining tools, rotating anodes	(None)	- The application of deep learning-based computer vision (DL-CV) enhances the sustainability of product-service systems,	- AI, particularly computer vision, creates opportunities for developing more sustainable product-service systems by enabling accurate wear assessments.

						specifically through better management of product wear states. -Implementing this technology leads to substantial reductions in CO_2 emissions for machining tools and rotating anodes by enabling more informed decisions on product usage, remanufacturing, and recycling. - Life cycle assessments confirm that utilizing computer vision for assessing wear decreases environmental impacts significantly, supporting sustainable practices.	-Accurate wear detection allows for extended product life through precise remanufacturing, reducing waste and resource use for machining tools and rotating anodes. The DL-CV approach enhances smart PSSs by integrating AI to support redesign, remanufacturing, and result-oriented services, fostering circular economy practices. -The technology provides detailed data that enhance decision-making in manufacturing and remanufacturing processes, contributing to sustainability goals by optimizing the usage phase of products.
46	Wang (2024)	Quantitative	312	-Firms adopting green and digital service innovations	A3-B5 B5-B6 B6-C4	- Both green and digital service innovations significantly enhance firm performance through improved product creativity, mainly focusing on effectiveness and novelty. - Green service innovations emphasize environmental sustainability, while digital	- Digital service innovations directly contribute to firm performance, enhancing customer satisfaction and operational efficiency, underpinned by digital technologies facilitating improved service delivery and customer engagement.

						service innovations enhance customer experiences. - Product effectiveness and novelty play critical mediating roles between service innovations and enhanced firm performance, highlighting the importance of creativity in leveraging the benefits of service innovations.	- Integrating green and digital service innovations leads to superior firm performance by fostering a sustainable competitive advantage that aligns with evolving market demands and environmental sustainability.
47	Wu et al. (2022)	Conceptual	1 case	-Collision-warning systems	B2-B3 B2-B6 B3-B2 B3-B6 B6-C3 B6-C4	- Developing a conceptual framework for an Extended Collision Warning System (ECWS), integrated with Smart PSS, connecting intelligent products and services to enhance road safety and transportation efficiency. - Real-time V2X communication and cloud processing reduce traffic accidents and delays, promoting safer and more sustainable urban mobility systems.	- The integration of digital technologies significantly improves vehicle and pedestrian safety by enhancing the responsiveness and accuracy of collision warning systems. - The system supports sustainability by reducing emissions, optimizing resource usage, and enhancing safety, aligning with circular economy principles and digital transformation goals.
48	X. Li et al. (2021)	Conceptual	1 example	-Sustainable development of 3D printers	A1-B5 A2-B5 B4-B6 B5-B4	- A data-driven reversible framework is proposed for Sustainable Smart Product-Service Systems (Smart PSS) that integrates cyber-physical resource management with	- Digital servitization serves as a strategy to achieve sustainability by enabling more efficient use and reuse of resources through

					B5-B6 B6-C4	product-service systems to enhance sustainability across the lifecycle of products. - It incorporates circular economy principles, enabling smarter reconfiguration, remanufacturing, reuse, and recycling strategies for extended product and service utility.	advanced data analytics and smart technologies. - Sustainable smart product-service systems can be developed by integrating smart technologies to enhance environmental and operational efficiency.
49	Xie et al. (2023)	Quantitative	195 enterprises	-Chinese manufacturing firms	A2-B* B6-C1 B6-C3 B6-C4	- Integrating digital technologies and servitization strategies (digital servitization) enhances manufacturing enterprises' sustainable development ability (SDA), positively impacting environmental, economic, and social dimensions. - Digital servitization improves resource efficiency, energy optimization, and operational profitability, supporting long-term sustainability goals despite initial implementation challenges.	- Combining digitalization and servitization (digital servitization) can be more beneficial than either approach alone in improving manufacturing enterprises' sustainability and overall performance. - Digital servitization offers synergistic benefits by integrating digital technologies with service-oriented business models, enhancing sustainability's economic, social, and environmental dimensions despite initial implementation challenges.
50	Zheng et al. (2019)	Qualitative/ Literature Review	97 papers	-Research articles on smart PSS	A1-B5 B4-B5 B4-B6	- This SLR highlights the convergence of digitalization and servitization into smart product-service systems (Smart PSS),	- The need for robust IT infrastructure to support Smart PSS is critical for effectively

					B5-B4 B4-B6 B6-C2 B6-C4	highlighting the transformative impact of ICT advancements on traditional business models. - It identifies key challenges, such as hybrid concerns in Smart PSS, and points to future directions, including self-adaptiveness, advanced IT infrastructure, and circular lifecycle management for sustainability.	integrating digital and service innovations, aiming at sustainable solutions. - Future Smart PSS are expected to incorporate self-adaptive technologies that enhance sustainability, focusing on efficient resource use and lifecycle management.
51	Zheng et al. (2020)	Conceptual	-	-Engineering lifecycle systems	B5-B6 B6-C4	- A systematic four-phase framework is proposed integrating industrial product-service systems with circular economy and smart enabling technologies like AI, IoT, and CPS: Sustainable industrial smart product-service system (ISPSS) - This novel framework is based on the ISO14001:2015 PDCA model and is introduced for sustainable lifecycle management, highlighting data-driven, context-aware decision-making. This approach confirms extended product lifecycles, better resource efficiency, and value co-creation among stakeholders.	- Digital technologies enhance the sustainability of industrial systems through better lifecycle management, from design to end-of-life. - Sustainable strategies, when combined with smart technologies (like AI and IoT), lead to more sustainable industrial solutions, supporting closed-loop systems and resource efficiency.

52	Zhu & Hu (2021)	Quantitative	1 case	-Car-sharing systems	A3-B5 B5-B6 B6-C1 B6-C3 B6-C4	- A novel rough-Z-number-based decision-making framework is introduced to evaluate sustainable value propositions (SVPs) for Smart Product-Service Systems (Smart PSS). - It directs how to handle uncertainty and reliability in stakeholders' judgments while evaluating SVPs. - Experimental case studies, such as on smart car-sharing systems, validate the framework's capability to enhance sustainability, stakeholder involvement, and innovation in Smart PSS development.	- Integrating digital technologies (IoT, AI, cyber-physical systems) in Smart PSS fosters sustainable innovation by enabling value co-creation and the circular economy. - The identified SVPs are aligned with the Triple Bottom Line (TBL) sustainability dimensions, emphasizing economic, environmental, and social outcomes.