SUSTAINABILITY THROUGH THE DIGITALIZATION: EXPLORING POTENTIALS AND DESIGNING VALUE CO-CREATION ARCHITECTURES FOR PRODUCT-SERVICE-SYSTEMS

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ABSTRACT

Digitalization and sustainability are major challenges for today's manufacturing industry. While digitalization is characterized by the incorporation of digital technologies in the products and services as well as the value creation architectures, sustainability requires them to balance economic, environmental and social issues. In both areas, especially Product Service Systems (PSS) are constantly gaining importance. This results in so called smart PSS that integrate digital technologies as well as sustainable PSS which aim at a positive impact on sustainability. Both two concepts cannot be clearly delimited since smart PSS might be designed for sustainability as well and sustainable PSS might be used with digital technologies. This paper aims to investigate the interrelations. To that, digitalization patterns of products and services are evaluated regarding their sustainable impact. The evaluation is conducted by a survey in research and industry. Furthermore, the design of the underlying value creation architecture is investigated. Here, a methodology is proposed enabling companies to optimize their value creation architecture.

Keywords: Product-Service Systems (PSS), Sustainability, Service design, Digitalization, Value Co-Creation

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Cite this article: Scholtysik, M., Reinhold, J., Koldewey, C., Dumitrescu, R. (2021) 'Sustainability through the Digitalization: Exploring Potentials and Designing Value Co-Creation Architectures for Product-Service-Systems', in *Proceedings of the International Conference on Engineering Design (ICED21),* Gothenburg, Sweden, 16-20 August 2021. DOI:10.1017/pds.2021.548

1 INTRODUCTION: SUSTAINABILITY AND DIGITALIZATION IN MANUFACTURING

For several years the sustainability discussion is intensely pursued concerning the global sustainable development as well as individual corporate social responsibility (Ebner and Baumgartner, 2006). The United Nations define sustainable development as an achievement for sustainable wellbeing for todays and futures generations. Key challenges to improve the sustainable development include among others the equality of humans, reduction of pollution and combating the climate change (Brundtland, 1987). This explanation extended the former understanding of the term "sustainability". Already in the late 1970s, the term sustainability emerged as a concept of environmental, economic, and social impact. These three dimensions comprise the so-called triple bottom line (TBL) which describes the core concept of sustainability (Elkington, 1997). The environmental dimension of sustainability mainly refers to balancing the earth's ecosystem (Glavič and Lukman, 2007). Hence, environmental sustainability pertains among others efficient use of energy recourses, reducing greenhouse gas emissions, minimizing the ecological footprint, etc. (Goel, 2010). The economic dimension of sustainability has been focused on long-term economic growth. This means in detail that the capability of economic grown is evolved for future generations (Elkington, 1997), (Spangenberg, 2005). The last dimension of the TBL is social sustainability. One primary objective is the establishment of health and wellbeing for communities without any discrimination and access to equal human rights (Dempsey *et al.*, 2011). Objectives of sustainability not only have a tangible relevance for today's society and governance, but the manufacturing industry as well. It is increasingly confronted by the megatrend sustainability (Mittelstaedt *et al.*, 2014), (Neckel, 2017).
Ongoing digitalization is fundamentally changing companies, and consequently many established business models (Bican and Brem, 2020). It opens access to new technologies, like artificial intelligence, machine learning or blockchain (Nakicenovic *et al.*, 2019). In general, digitalization can be classified as an enabler to improve the manufacturing sustainability in terms of resources efficiency and manufacturing performance. To achieve these objectives, data and a comprehensive data infrastructure are needed as a basis (Gürdür *et al.*, 2019). Kylmenko and colleagues note that the data available to companies is not sufficient to achieve significant impact on environmental sustainability (Kylmenko *et al.*, 2019). However, the progressive introduction of information and communication technologies enables the collection and transmission of more essential data, e.g. energy consumption, to create more sustainable products (Gensch *et al.*, 2017). Hence, there is a need for digitalization measures to obtain the necessary data (Kylmenko *et al.*, 2019). Beside the important need of data, digital technology innovations are important as well. In particular, the circumstances are decisive in determining whether a technology has a sustainable impact. As an example, electric vehicles offer potentials to reduce emissions and pollution but as soon as the electricity power comes from unsustainable procedures the contribution to sustainability declines (Nakicenovic *et al.*, 2019). The general relations between digital transformation and sustainability are investigated by Bican and Brem. Their investigation confirms the statement that digital technologies are an important part to improve sustainability in today's manufacturing industry (Bican and Brem, 2020). In general, the literature agrees that digitalization and sustainability cannot be contemplated in isolation. An integrated view of both trends is needed (Nakicenovic et al., 2019), (Gürdür *et al.*, 2019).
When focussing on digitalization and sustainability in manufacturing one significant lever is the concept of product-service-systems (PSS). Here, the research question arises, how digitalization and sustainability are interconnected in design, and how exploring potentials of digital technologies might help realizing sustainability effects.

2 SUSTAINABILITY AND DIGITALIZATION IN PSS

PSS in general are marketable sets of products and services capable of jointly fulfilling a user's needs (Goedkoop *et al.*, 1999). Until recent, products were often considered separately from services (Baines *et al.*, 2007). Hence, PSS represent a relatively new understanding of solutions (Stark *et al.*, 2014). One of the first definitions of PSS by Mont already integrated aspects of sustainability: "Thus, a PSS should be defined as a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models." (Mont, 2002). This is quite controversial, Tukker and Tischner for

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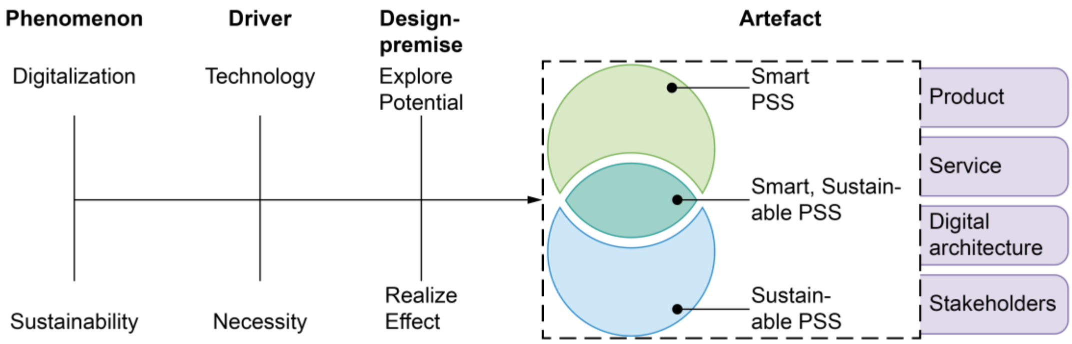
example regard the statement, that PSS equal sustainability as a myth. They argue that PSS enhance the degree of freedom to find and realize improvements in sustainability (Tukker and Tischner, 2006). Henceforth, to achieve an environmental impact, it is important that PSS are specifically designed for sustainability (Tukker and Tischner, 2006), (Baines *et al.*, 2007). Such PSS can be subsumed under the term Sustainable PSS (SPSS). Additionally to the understanding of PSS, SPSS are focused on environmental and socio-ethical benefits while also satisfying the economic interest of the provider (Vezzoli *et al.*, 2015). For that, SPSS are especially designed, marketed and developed to create environmental sustainability (Vezzoli *et al.*, 2014). For example, the ecological efficiency within the whole product lifecycle is emphasised (Vezzoli *et al.*, 2018). Besides the potential of PSS to enhance sustainability, another key challenge for today's manufacturing industry is the digitalization (Parviainen *et al.*, 2017). In the course of the emerging digitalization megatrend, companies are currently incorporating more and more digital technologies into the design and delivery of their PSS (Chowdhury *et al.*, 2018). Products become hybrids consisting of physical and digital components (Fleisch *et al.*, 2015). They comprise of hardware, sensors, data storage, microprocessors, software, and connectivity; thus turning them into smart, connected products (Porter and Heppelmann, 2014). The resulting ubiquitous availability of data creates vast opportunities for service innovation (Böhmann *et al.*, 2014). Besides traditional services like maintenance or consulting new digitally enhanced services are now possible within PSS. For that, digital architectures linking the stakeholders like IoT-platforms are needed in a PSS architecture (Blüher *et al.*, 2019). This extends the freedom to integrate intelligent products or advanced digital services as parts of PSS (Lerch and Gotsch, 2015), (Zambetti *et al.*, 2019), (Herterich *et al.*, 2015). Such PSS are often referred to as Smart PSS (Chowdhury *et al.*, 2018), (Valencia *et al.*, 2015). They differ from traditional PSS through their high degree of automation and inherent intelligence (Lerch and Gotsch, 2015). Such Smart PSS comprise of four characteristic design elements: products, services, digital architecture, and stakeholder. Therefore, the development of smart PSS includes technical aspects as well as the interactions between stakeholders. (Blüher *et al.*, 2019), (Blaschke *et al.*, 2019). Zheng and colleagues differentiate between three levels of Smart PSS: the product-service level, the system level and the system of systems level. With each level the scope of the PSS extends leading to ever more complexity in each element (Zheng *et al.*, 2019). Each of the four design elements of Smart PSS may contribute to the goal of sustainability on each level of consideration.

While the emergence of smart PSS is driven by technology, the importance of sustainable PSS is rising by necessity. This reflects in the fundamental design premises of both concepts; designing smart PSS tends to explore the potentials of digital technologies, while the design of sustainable PSS is focused on the realization of positive effects on economical, ecological, and social issues.

The two concepts cannot be clearly delimited since smart PSS might be designed for sustainability as well and sustainable PSS might use digital technologies. Hence, we propose that there is a subset of PSS that use digital technologies to achieve impacts to benefit sustainability. We call them smart, sustainable product-service-systems and define them as PSS, that use digital technologies to realize sustainable benefits. Figure 1 shows the resulting understanding of the three concepts of smart, sustainable, and smart, sustainable PSS.

In the following, the four design elements of smart PSS according to Blüher and collegues are investigated regarding their impact on sustainability. This is done in twofold ways. First the product and the service elements are investigated measuring the impact of digitalization patterns on sustainability (Chapter 3). Next a method to plan the digital architecture and the stakeholder relations



is introduced. For that the value network approach is extended (Chapter 4).

Figure 1. PSS Concepts in conjunction of Digitalization and Servitization

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3 PRODUCTS & SERVICES: EXPLORING DIGITAL PRINCIPLES FOR SUSTAINABILITY

The interrelation between digitalized products and services and the dimensions of the TBL are investigated in the following. This chapter provides a exploratory overview of the sustainable potential by product and service components of PSS. For that we combined two approaches of innovation principles for digitalization: Echterfeld proposes 52 principles divided into the three dimensions product (e.g. user authentication), service (e.g. location-based services), and business model (e.g. pay-per-use) (Echterfeld, 2020), while Koldewey introduces 30 principle functionalities for digital services based upon product data (benchmarking, predictive maintenance etc.) (Koldewey, 2021). We compare all 82 principles to eliminate possible redundancies. In total, 66 innovation principles for digitalization remained. To measure their sustainability impact generally, we created a questionnaire which was addressed at research institutes and company representatives. The research approach is structured into three studies. First, we determine necessary data from the answered questionnaires (descriptive study). Second, we analyse the interrelationships between the data from the respondents (explorative study). Last, we interpret all considered data to deduce the sustainable impact of the digitalization principles (inductive study) (Leavy, 2017).

At the beginning of the descriptive study, we informed the respondents that they would need approximately 40 minutes to complete the questionnaire. Furthermore, the questionnaire instructions informed the respondents about the aim, the rating scale and provided definitions of the environmental, economic, and social dimension as well as a definition for each principle. The definitions are phrased as questions and refer to the understanding in chapter one. As an example, the question regarding the environmental sustainability was formulated as follows: "Does the considered digitalization principle is enhancing the earth's ecosystem? (e.g., efficient use of energy resources or reducing greenhouse emissions)". The participation was anonymous. In total, 17 people completed the questionnaire. Eleven researchers and six company representatives from a wide range of industries (from management consulting to classical mechanical engineering) participated.

All 66 digitalization principles were rated individually towards each dimension of the triple bottom line (environmental, economic, and social). For this, the evaluation of the questionnaire is based on a five-point Likert scale (Likert, 1932). It ranged from 0 ("no impact at all") to 4 ("great impact"). This enables comparability between different digitalization principles and suggests a general estimate of the holistic sustainable potential. Further, it is possible to identify the sustainability intensities of the TBL-dimensions for each principle. Table 1 shows the innovation principles considered as well as their evaluation in terms of means and standard derivations. We defined the border of a sufficient sustainability impact at a rating of two, and upwards. Consequently, principles with a rating of two, and upwards in all dimensions of the TBL are classified as a sustainable digitalization principle.

With the survey, we want to answer two main research questions. First, we investigate whether the presented digitalization principles have a holistic impact for sustainability. For that, we calculate the arithmetic mean of each dimension for the considered principle. Second, the results answer the question, which dimension of the TBL is influenced significantly by digitalization. Therefore, we considered each dimension in isolation and calculate the arithmetic means of all ratings. The first question is answered categorizing the digitalization principles in four categories. The categories differ by the number of sustainability dimensions that received an averaged rating of two, and above. The results of this evaluation are illustrated in figure 2.

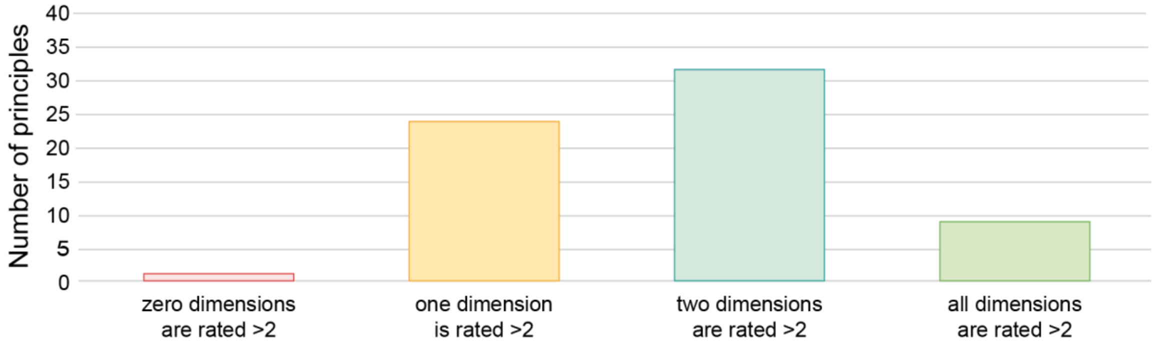

Figure 2. Overall sustainability contribution of digital innovation principles

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Table 1. Overview of the principles and results of the evaluation

Principle	Source		Rating							
			economic		environ-menta		social		overall	
	ECHTERFELD	KOLDEWEY	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Data Management		x	3,00	1,12	1,47	0,87	2,00	1,12	2,16	0,78
Document Management		x	2,47	1,18	2,12	1,17	2,00	1,41	2,20	0,24
Network Building	x	x	2,94	0,97	2,00	1,00	2,00	1,17	2,31	0,54
Communication		x	2,29	0,99	1,41	1,18	2,82	1,01	2,18	0,71
Data Provision		x	2,29	1,05	1,71	1,05	2,29	1,31	2,10	0,34
Status-Monitoring	x	x	2,47	1,07	2,35	1,22	1,50	0,71	2,11	0,53
Consumble-Monitoring	x	x	2,44	1,26	2,65	1,27	1,56	1,23	2,22	0,58
Usage-Monitoring		x	2,71	1,16	2,41	0,94	1,82	1,13	2,31	0,45
Process-Monitoring		x	2,88	0,99	2,06	1,09	1,35	1,00	2,10	0,77
Porfiling & Behaviour Tracking	x	x	2,59	1,28	1,65	1,22	2,18	1,29	2,14	0,47
Asset Mapping		x	2,59	1,18	2,53	1,28	1,76	1,39	2,29	0,46
Fleet Management	x	x	2,94	1,25	2,69	1,18	1,25	1,07	2,29	0,91
Benchmarking		x	2,88	1,22	1,29	1,10	1,29	1,10	1,82	0,92
Information Brokering		x	2,29	1,16	1,24	1,03	2,12	1,36	1,88	0,57
Service Support	x	x	2,35	1,00	1,53	1,18	2,71	1,36	2,20	0,60
Alerting		x	2,00	0,94	1,59	0,94	2,41	1,18	2,00	0,41
Predictive Maintenance	x	x	3,29	0,92	2,06	1,20	2,06	1,20	2,47	0,71
Operator Support		x	2,00	0,79	1,18	0,88	2,65	1,22	1,94	0,74
Diagnostics		x	2,82	0,88	1,88	1,05	1,88	1,20	2,19	0,55
Analytics Dashboard		x	2,35	1,06	1,41	1,06	2,41	1,23	2,06	0,56
Advanced Reporting		x	3,06	1,20	2,00	1,12	2,00	1,22	2,35	0,61
Remote Control		x	2,76	0,90	2,29	1,21	2,94	1,03	2,67	0,33
Resource Scheduling		x	2,65	1,06	2,71	1,26	2,12	1,11	2,49	0,32
Automatic Order	x	x	2,65	0,93	1,41	1,23	2,24	1,03	2,10	0,63
Simulation	x	x	2,53	1,28	2,59	1,37	1,53	1,12	2,22	0,60
Input Optimization	x	x	2,88	1,27	3,24	0,97	1,59	1,18	2,57	0,87
Process Optimization	x	x	3,24	0,90	2,76	1,03	1,88	1,22	2,63	0,69
Output Optimization	x	x	3,12	0,99	2,24	1,25	1,29	0,85	2,22	0,91
Updates & Upgrades	x	x	2,24	1,15	1,53	1,01	1,71	1,16	1,82	0,37
Automation		x	2,82	1,07	2,24	1,15	2,06	1,03	2,37	0,40
Digitization of HMI	x		1,94	1,14	1,35	1,27	3,12	1,11	2,14	0,90
Substitution of hardware by software variants	x		2,71	1,16	2,59	1,23	1,41	1,28	2,24	0,72
Digitization of bills	x		2,59	1,06	2,18	1,07	2,18	1,29	2,31	0,24
Digitization of paper documents	x		2,29	0,99	3,06	1,14	2,12	1,22	2,49	0,50
Digitization of analogue images	x		1,88	1,17	1,94	1,20	2,06	1,09	1,96	0,09
Outsourcing of functions to the cloud	x		2,59	0,94	1,88	1,17	1,71	1,40	2,06	0,47
Elimination of disturbance variables	x		2,19	1,20	1,63	1,01	1,44	1,06	1,75	0,39
Authentication of the user	x		1,71	1,21	0,76	0,97	2,18	1,51	1,55	0,72
Authentication of the components	x		2,59	1,06	1,18	1,24	1,06	0,90	1,61	0,85
Adaption to the product settings	x		2,47	1,12	1,88	1,36	2,06	1,14	2,14	0,30
Self learning product	x		2,71	1,16	1,94	1,20	1,94	0,90	2,20	0,44
Individualisation of the user interface	x		1,65	1,17	0,88	0,93	2,53	1,23	1,69	0,82
Digital activation of product features	x		2,65	1,22	1,35	1,27	1,65	1,32	1,88	0,68
Control System on third party devices	x		1,88	1,11	1,59	1,18	1,88	1,11	1,78	0,17
Realisation of functions by integration of external products	x		2,24	1,30	1,71	1,10	1,29	1,21	1,75	0,47
Creation of an operating system of all products	x		2,59	1,18	1,71	1,16	2,29	1,10	2,20	0,45
Automatic control of products by other products	x		2,18	1,01	1,35	1,06	1,88	0,99	1,80	0,42
Automatic control of a product into a product system	x		2,41	0,94	1,18	1,01	2,12	1,27	1,90	0,65
Optimisation of product systems	x		2,88	1,17	2,47	1,01	1,65	1,06	2,33	0,63
Visual decision support for product purchase	x		2,24	1,15	1,18	1,29	2,06	1,34	1,82	0,57
Provision of digital models of products	x		2,29	1,05	2,12	1,17	1,94	0,90	2,12	0,18
Integration of external services into the product	x		2,29	0,92	1,76	1,39	1,47	1,33	1,84	0,42
Providing a development setting for digital services on products	x		2,29	1,16	1,06	1,03	1,71	1,16	1,69	0,62
Sale of the use of the product (Pay per Use)	x		2,59	1,28	2,12	1,45	1,71	1,31	2,14	0,44
Sale of the performance provided with the product	x		2,65	1,22	2,12	1,45	1,88	1,17	2,22	0,39
Flat rate based billing	x		2,41	1,12	1,18	1,19	1,53	1,28	1,71	0,64
Offer of a free basic and cost-liable premium product	x		2,29	1,16	0,88	0,93	1,29	1,05	1,49	0,73
Sale of the product by subscription	x		2,24	1,09	0,94	0,97	1,41	1,12	1,53	0,66
Rental of the product	x		2,31	1,33	2,13	1,46	1,67	1,12	2,03	0,33
Razor and Blade	x		2,13	1,12	1,19	1,17	1,19	0,99	1,50	0,54
Sale of additional features and services at extra charge	x		2,44	1,21	1,13	0,90	1,25	1,01	1,60	0,72
Operating model	x		2,53	1,28	1,71	1,10	1,82	0,95	2,02	0,45
Development of a digital service business	x		2,38	1,15	1,44	1,06	1,81	1,21	1,88	0,47
Creation or joining a digital transactions platform	x		2,82	1,01	1,65	1,27	1,88	1,27	2,12	0,62
Overall Mean			**2,5**	**1,11**	**1,81**	**1,15**	**1,89**	**1,16**	**2,06**	**0,55**

In total, there are 41 principles (62%) which are rated above two in at least two dimensions of the TBL. Thereof, the respondents rated nine of the investigated principles with a holistic sustainability impact meaning that all dimensions received a rating of two or more. Remote Control is one of these.

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According to Koldewey, Remote Control is defined as the possibility to view or edit process or control data of e.g. smart products and optimize them remotely (Koldewey, 2021). Only one principle (Control System on Third Party Devices) is rated without any significant impact. 24 principles have an impact of two or more for one sustainability dimension. The comparison between the evaluation of researchers and company representatives clarifies that industry representatives (17 principles with a holistic impact for sustainability) tendentially associate digitalization principles with sustainability more intensively than research representatives (7 principles with a holistic impact for sustainability). Nevertheless, the focus of both respondent groups on significant digitalization principles is very similar. In total, four of the five highest rated principles are represented in both groups. These results indicate an essential finding. Generally, digitalization and its principles have the potential to improve sustainability in today's industry. But not all principles contribute equally. Hence, the results suggest that digitalization is an important enabler, but not a decisive driver for sustainability. As a next step we investigate which dimension of sustainability is significantly influenced by the digitalization. For that, the sustainability dimensions were analyzed individually. A histogram shows the distribution of the principles in six intervals representing the evaluation regarding sustainability in each of the dimensions and overall (Figure 3). The intervals are starting from zero to one and can be characterized as left-closed, right-open. The next intervals are covering a range of 0,5 with the same characteristics. The last interval is a closed interval ranging from 3 to 4. This was chosen to have a higher resolution in the relevant value range and not to emphasize the extremes.

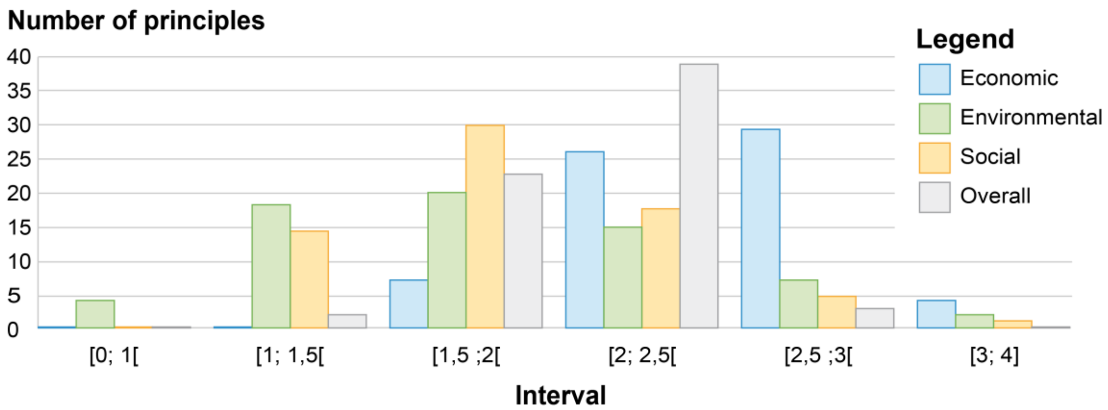

Figure 3. Histogram of the principles focused on the dimensions economic, environmental, social and overall impact

The first finding of the histogram is that the course of the environmental and social dimension are similar. Both peaks are located in the interval [1,5;2[. In contrast, the peak of the dimension economic is prescribed in the interval of [2,5;3[. This shows that the economical dimension is influenced more intensively by digitalization than the social and environmental dimensions. This is confirmed by the calculated average of all ratings. In particular, the calculations clarify that the environmental (mean: 1,81) and social (mean: 1,89) dimensions are similar regarding their overall effect. The economic dimension (mean: 2,5) is standing out. Even if the average rating of environmental and social is below the defined sustainability threshold, the overall histogram exemplifies that 41 (62%) digitalization principles are rated with two or higher. Consequently, it can be concluded that digitalization has a particular impact on the economic dimension. Nevertheless, there are strong tendencies to promote the environmental and social sustainability. The limited number of participants do not allow a manifested statement of the sustainable impact by the presented digitalization principles. There is more future work needed to analyze the sustainable impact in depth (e.g., interviews or a case study).

4 VALUE-CO CREATION: DESIGNING DIGITAL VALUE CREATION SYSTEMS FOR SUSTAINABILITY

As we base our study on the work of Blüher and colleagues, there are two more aspects of smart PSS to be considered (Blüher *et al.*, 2019). While chapter three analyzed the implications of the digitalization of products and services on sustainability, chapter four focuses the digital architecture and stakeholders of smart sustainable PSS. Companies that use digital principles to compete and at the same time pursue sustainability goals are increasingly creating value through co-creation (Blaschke *et*

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al., 2019). Value co-creation refers to the sharing of value creation processes, activities and resources between different actors that cooperate in an ecosystem (Lusch and Nambisan, 2015). This approach originally comes from the theory of service-dominant logic, became more important with the emergence of digitalization and is now used as a basis for designing sustainable value creation systems (Li *et al.*, 2020). The complexity of these value creation systems is increasing, especially due to the growing number of changing actors, varying interactions and distributed competences. Against this background, an approach is needed that makes the complexity manageable and enables the design and analysis of digital value creation systems for sustainability.

To develop the approach we used the Design Research methodology (DRM) introduced by Blessing and Chakrabarti (Blessing and Chakrabarti, 2009). The DRM is divided into four consecutive phases: Clarifying of the research goal, conducting a first descriptive study I, conducting a prescriptive research goal and conducting a second descriptive study II (Blessing and Chakrabarti, 2009). As a result, we propose a specification technique for the design and analysis of value creation systems according to (Schneider, 2018) that is extended for the design of hybrid value creation in the context of complex socio-technical systems in the joint research project Instruments for pattern-based planning of hybrid value creation and work for the provision of smart services (IMPRESS). Subsequently, we adapt this specification technique to the specifics of sustainable value creation. It enables a concise, graphical modelling of a value creation system and serves as an instrument for a clear analysis and integrative planning.

The modelling of sustainable value creation systems is done threefold. First, basic constructs for the value creation system have been defined and specified. The basic constructs distinguish between value creation entities, processes, and resources. Value creation entities describe defined points in a value creation system that execute at least one relevant business process, are responsible for it, provide the required resources or are related to other entities. For example, a logistics service provider acts as a key partner in the transport of a product from a manufacturing company to a customer. Second, the relationships between the basic constructs must be set. Thereby, different value creation entities can be linked or grouped together. A distinction is made here between flows that describe the exchange of information, products and services, and financial transactions. Last the modelled value creation system is analyzed for sustainability potential. For that, additional constructs are used to detail basic constructs or relationships. They support the intuitive understanding of described relationships and may be used to point out specific value potential.

With the help of the modelling concept described above, value creation structures can be modelled and analyzed in the context of sustainability. Thereof, future sustainable value creation systems can be planned. In the following, the application of the specification technique is demonstrated using the example of remote control as this is rated as a sustainable digitalization principle referring to previous chapter. Figure 4 illustrates the analysis of the existing value creation system of a considered company on the left as well as its value design on the right.

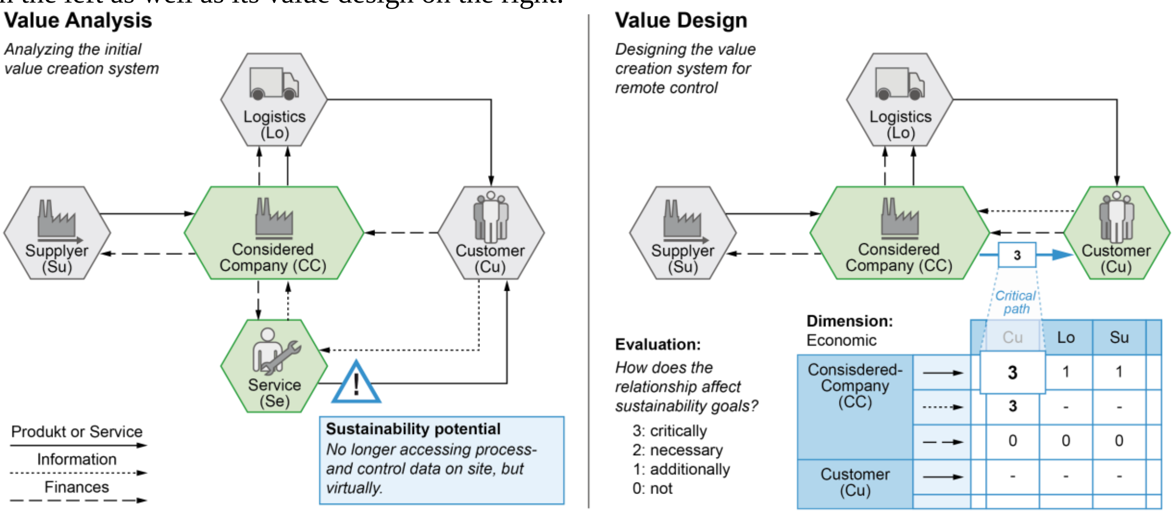

Figure 4. Value analysis and design of a value creation system for sustainability by the example of remote control (excerpt)

In this example, the relationships between the actors are examined for sustainability potentials as illustrated on the left part. For example, the relation between Service and Customer offers potential for

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sustainability. Here, the physical interaction of accessing data on site could be replaced by a virtual interaction in order to save resources as well as effort. On the right, the design of the future value creation system oriented towards sustainability is illustrated. The entity Service is omitted and the Customer itself takes its role as a key partner in the value creation system. To ensure that the future value creation system is designed for sustainability aspects, the relationships between all entities are evaluated as illustrated. The question How does the relationship affect sustainability goals? may be answered with critically, necessary, additionally, or not. Especially critically affecting relationships come into focus designing the future value creation system since they determine critical paths in the value creation system (Reinhold *et al.*, 2019). Without implementing and maintaining these relationships, the considered company's sustainability goals are more likely to be missed.

5 DISCUSSION

Various recent studies have investigated whether digitalization is an enabler for sustainability and how PSS can be used for sustainability (Gürdür *et al.*, 2019), (Gensch *et al.*, 2017), (Kylmenko *et al.*, 2019), (Tukker and Tischner, 2006), (Roy, 2000). The respondents of our questionnaire rated only a limited number of digitalization principles (nine from 66 principles) with a holistic impact on sustainability. Admittedly, this result confirms the hypothesis of Tukker and Tischner that digitalized PSS have no obligatory impact on sustainability (Tukker and Tischner, 2006). However, the limited number of participations of the questionnaire leads to the finding that, the number of nine sustainable digitalization principles are only an initial assessment for sustainability through digitalization. For a detailed answer which digitalization principle creates a sustainable impact, there are more participants needed. Additionally, the questionnaire might be supported by interviews with digitalization and/or sustainability experts. Nevertheless, the distribution of the rated principles (61% rated in minimum two dimensions by two, upwards) indicates that standardized digitalization principles must be specially designed for sustainability. This finding corresponds with the investigation by Vezzoli and colleagues (Vezzoli *et al.*, 2014). The investigation by Bican and Brem postulates an impact on the economic and environmental dimension through the digital transformation. Through our survey, it is possible to examine the intensities of the sustainability dimensions which are influenced by the digitalization in PSS. In general, the responses show that all dimensions of sustainability might be strengthened by digitalization. However, the economic dimension is clearly most affected by digitalization. With the rapid progress of digitalization, data are an irreplaceable aspect of digitalized PSS. According to Kylmenko et al. and Gürdur et al., data enables sustainable value creation (Kylmenko *et al.*, 2019), (Gürdür *et al.*, 2019). Due to the high overall rating of the digitalization principles, the importance of data can also be derived by the evaluation. Hence, our study confirms tendencies in literature regarding digitalization and sustainability with an emphasis on PSS.
However, it remains to be examined whether the digitalization principles as mentioned in Chapter 3 can be transferred to value creation systems as well or whether completely new digital value creation principles emerge. With this in mind, the examination of value creation design principles frequently proposed in the literature, e.g. in (Blaschke *et al.*, 2019), with regard to aspects of sustainability is a logical next step.

6 CONCLUSION

Considering the results presented in this paper, we investigated common principles for digitalization regarding sustainability and how these principles can be realized in value creation systems. First, a questionnaire was introduced to figure out which digitalization principles by Echterfeld and Koldewey have an impact for sustainability. In total, 17 respondents completed the presented questionnaire. In general, the questionnaire provides three findings: 1) Principles for digitalization are not necessarily associated with a sustainable benefit. 2) Industry and research have very similar assessments of the sustainability potential of digitalization principles. 3) Especially economic dimension of the triple bottom line is promoted by the digitalization. Based on the limited number of participations, additional research for validation is needed. It requires e.g., more participants, an additional interview series or a case study to concretize the presented results. Another aspect for future research is the linkage between sustainable digitalization principles. Second, we proposed an approach for the design of sustainable value creation systems. It includes three constructs: basic constructs, relationships and additional constructs. Furthermore, the approach allows for the analysis of relationships in a value

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system with regard to sustainability. Hence, it provides a first approach for the quantification of sustainability in value creation systems. Future research should investigate whether a mathematical model can be used to design and optimize value creation systems in terms of sustainability. The approach shown provides a solid basis for this. As a concluding remark our paper indicates that digitalization and sustainability go well hand in hand. But we suspect that there is no strong deterministic connection.

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