Industrial product service system and environmental sustainability, main challenges and opportunities: a literature review

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Abstract: Industrial product service systems (IPS2) are systems in which products and services are integrated to deliver value in industrial applications. When proposing an IPS2, companies integrate investment goods and industrial services along their lifecycle. IPS2 are often considered a promising paradigm to achieve higher environmental sustainability. Those configurations can decouple value production from resource consumption, in line with the principles of circular economy (CE). In successful configurations, products are designed for a longer lifecycle, optimized thanks to the implementation of services. In addition, the production of waste is reduced, and the usage of energy and resources is optimized. IPS2 are often supported by digital technologies and integrated services can be designed and implemented by leveraging data captured from the products. Nonetheless, IPS2 are not more sustainable than the traditional alternatives by default. IPS2 must be designed and operated with the objective of guaranteeing not only economical sustainability, but also environmental sustainability; otherwise IPS2 offerings could be more environmentally impactful than traditional configurations. Manufacturing companies which are interested in pursuing the servitization paradigm should strategically design and implement IPS2 offerings to achieve both the satisfaction of customers' requirements and the expected environmental impact improvements. Even though the relevance of IP2 for sustainability is recognized by the literature, few studies focus on the topic and approach it in a structured way. In this paper, the authors aim at covering this gap, investigating, through the execution of a systematic literature review, the current state of the art related to industrial product service systems, sustainability and circular economy. The authors offer an analysis of major challenges and opportunities for the design and application of sustainable IPS2, focusing in particular on best practices and the role of digital technologies.

Keywords: Industrial Product Service System (IPS2); Sustainability; Circular Economy

I. Introduction

An industrial product service system (IPS2) is defined as "*a systematic package in which intangible services are attached to tangible products to finish various industrial activities in the whole product life-cycle*" (Jiang & Fu, 2009). IPS2 are product service systems (PSS) applied in the B2B industrial environment (Meier et al., 2010). Nowadays, servitization is a highly common trend adopted by manufacturing companies (Landolfi et al., 2019). Two additional growing trends in manufacturing are sustainability and circular economy (CE), intended as "*an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes*" (Kirchherr et al., 2017). IPS2 are believed to slow and close resource loops, contributing to CE.

It is recognized that IPS2 could offer valuable contribution to economic, environmental, and social sustainability. Economical sustainability can be reached by shifting the business model from selling product to add service offering, thus increasing profits (Meier et al., 2010). IPS2 can impact social sustainability enabling high-wage countries to provide new jobs and protect employment (Meier et al., 2010). For what concerns environmental sustainability, the main expected contribution of product service systems (PSS) to sustainable manufacturing and consumption, originates from the higher responsibility of providers for their offerings. PSSs' providers profit from low lifecycle costs and expanded product's lifespan, therefore they are influenced in applying a more efficient usage of materials (Matschewsky, 2019). Even though the PSS business model is often recognized as a viable option to pursue circular economy, PSS should be designed and implemented with great care. In order to reduce environmental impact, PSS offering should be intentionally design with the objective of sustainability (Michelini et al., 2017). PSS offerings are not inherently more sustainable than traditional offerings (Tukker, 2015). Current literature mostly focuses on the general concept of PSS; few studies analyze the sustainable dimension of IPS2, which barriers should be overcome, and which characteristics could be leveraged to achieve sustainability.

This paper focuses on the topic of IPS2's environmental and social sustainability and circular economy, with the objective of identifying the main barriers and opportunities, the covering current existing gap in the literature. In section 2 the authors offer an overview of existing literature on the topic of PSS and sustainability. In section 3 the research objective and methodology are explained. In section 4 the results of the research are presented and then are discussed in section 5. In section 6 the main are reported the main conclusions of the study.

II. Theoretical Background

This paragraph focuses on the existing literature on PSS in relation to sustainability. It is possible to see that even though the topic of PSS's sustainability is a very popular one, few papers focus on PSS industrial declination IPS2.

The first definition (Annarelli et al., 2016) linking PSS and sustainability comes from (Mont, 2002) "*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.*"

Many authors studied the sustainability of PSS solutions against the traditional counterparts, yet, most studies focus on the economic sustainability, which is out of scope for this paper. PSS solutions were developed to increase price differentiation, selling spare parts and additional services evolved into an integrated offering of products and services (Pieroni et al., 2017). Nonetheless PSS can contribute to improve environmental and social sustainability as well. Even though sustainability is recognized as crucial, few design methodologies focus on those, and none focus on the social dimension (Pieroni et al., 2017).

A review from Tukker A. (2015) illustrates that many papers study the topic, and that PSS are not a sustainability panacea. In B2C context, the comfort, convenience, and experience of owning the product often bring customer in not choosing the PSS (Tukker, 2015). Moreover, PSS have different environmental sustainability opportunities based on the typology of PSS implemented. Product-oriented PSS, in which services integrate the product, do not automatically incentivize the maximization of product sale. Use-oriented PSS, in which the provider retains the ownership of the product while selling the access to the resource, intensify the usage of material, but products could be used less carefully by clients. Result-oriented PSS, in which the results of the product are sold, offer the higher opportunities for sustainability, but the high economical costs could hamper their implementation, thus reducing the overall impact (Tukker, 2015).

(Kjaer et al., 2019) identify five strategies through which PSS can help in the reduction of resources, linking PSS to CE.

- The operational support strategies in which the PSS provider supports the product operation through services such as monitoring or training.
- Product maintenance strategy in which the provider supports the product during use through preventive maintenance, repair, or upgrades.
- Product sharing strategy in which the provider retains the ownership sharing resources among users.
- Take-back/End of Life (EoL) management strategy through which the provider takes care of products' EoL and manages the reusage, remanufacturing, refurbishing, and recycling.
- Optimized result strategy, through which the provider dematerializes the offering delivering functional results.

Multiple authors propose lifecycle assessments (LCA) to study the environmental impact of PSS against their traditional alternatives. In (Lindahl et al., 2014) three PSS show reduced environmental impact through increased use time, reutilization rate, and recycling. This sustainable improvement is caused by the motivation of producers to design durable products to reduce maintenance and repair costs and to maintain products conditions to facilitate those activities. (Fargnoli et al., 2018) confirm that PSS can improve environmental performances, by reducing consumed resources and improving end-of-life strategies. (Kaddoura et al., 2019) study the decreased environmental impact achieved through the implementation of services to extend the lifecycle of products. Nonetheless, the implementation of PSS does not guarantee improved environmental performances. (Zhang et al., 2018) show that the environmental impact of PSS is highly dependent from its configuration, and it could actually decrease the sustainability in relation to traditional offers. Certain configurations could indeed require additional activities, such as transportation, which have high environmental impact (Martin et al., 2021).

Existing literature identifies in increased sustainability one of the main perks of PSS, which must be design accordingly to achieve true sustainability. The previously mentioned studies analyse the general concept of PSS, often without differentiation between the B2B and B2C contexts, and do not capture the unique characteristics of IPS2.

III. Methodology

The objective of this study is to investigate the impact of IPS2 on social and environmental sustainability. As stated in the previous paragraph, the current literature does not focus on the impact of IPS2 on environmental sustainability. The authors, with this research aim at covering the identified gap. The paper aims at identifying barriers and opportunities to achieve sustainability, by implementing PSS in an industrial context.

To answer this objective a Systematic Literature Review (SLR) has been carried out. The authors used the Scopus engine with the research query: TITLE-ABS-KEY *(("industrial product service system" OR "Industrial product service" OR "manufacturing as a service" OR ips2 OR "industrial servitization" OR "industrial servitisation") AND (sustain* OR "circular economy"))*. The collection of paper ended on the 1st of May 2023. The initial pool of paper was constituted by 50 papers, the authors then proceeded with a first cut based on title and abstract selecting 30 papers, a final cut based on full text reading allow to select 19 eligible papers for the analysis. The relevant papers were selected based on pertinence with the research objective, in particular the papers had to investigate the manufacturing context and study IPS2's sustainable impact not only from the economic perspective but on the environmental or social dimension as well.

IV. Literature review results

IPS2 offer opportunities to achieve significant sustainability in production and consumption. The sustainability potential encompasses the new types of stakeholders' relationships and the opportunity of systemic optimization of resources (Ding et al., 2017). IPS2 can potentially improve resource utilization, higher capacity utilization, and reducing the number of products in use (Kusiak, 2022; Reim et al., 2014).

The implementation of IPS2 configuration does not automatically translate into environmental benefits, to achieve environmental sustainability companies must actively strive to achieve it (Ding et al., 2017; Guidat et al., 2014)

From the analysis of the papers the authors identified the main challenges and opportunities to achieve positive sustainable impact through the implementation of IPS2.

A. Challenges

a) Complexity and Uncertainty

Literature finds in the level of complexity and uncertainty one barrier for the achievement of sustainability in IPS2. Companies interested in servitization should be able to predict and manage uncertainty (Brissaud et al., 2022), the adequate management of system uncertainties could improve the way resources are used (Erkoyuncu et al., 2019). Thus, uncertainties should be factored into service contracts regulating IPS2 activities (Erkoyuncu et al., 2019). The main sources of uncertainties recognised by (Erkoyuncu et al., 2019) are the management of the entire product lifecycle, quality and reliability of the offering, the behaviour and structure of systems, the volatility of corporate culture and the changing value, influenced by the evolution of customer needs and scope of operations.

The high level of complexity and uncertainty impacts in particular scheduling activities, as studied by (Ding et al., 2017). The delivery of resources based on scheduling results not only impact the customer satisfaction, but also product service sustainability and environmental impact. IPS2's resources are fluid and heterogenous, leading to confusion and inefficiency for suppliers

(Ding et al., 2017). For this reason, IPS2's scheduling is both a crucial and challenging activity.

Additional elements of complexity that could hinder the achievement of environmental sustainability are the systems on which IPS2 rely: the role and boundaries of each stakeholder may limit the potential for environmental improvements (Guidat et al., 2014)

b) Trust between partners

IPS2 configurations require a high degree of trust between suppliers and clients. Indeed, to carry on optimization activities such as maintenance, the suppliers rely on data captured by the equipment their clients are using (Schroeder et al., 2022). The trust between partners is particularly relevant in those IPS2 configurations requiring the outsourcing of customers' processes to suppliers, which only few customers are willing to do (Pessôa & Becker, 2017). The success of IPS2 depends also on the capacity to clarify customers' requirements and to propose service-oriented information campaign informing customer about the potentiality of the integrated offering (Nag et al., 2022).

c) Increased impact

IPS2 offerings are characterized by services and additional activities (such as transportation), which could increase energy consumption reducing environmental sustainability (Ziout & Azab, 2015). Moreover, even though the offerings achieve improved utilization rate, this could not translate into lower impacts, if the using hours of products stay the same (Pessôa & Becker, 2017).

d) Long systems' lifecycle

PSS is considered a viable option to avoid both objective and subjective obsolescence of products, thanks to the offering of additional services (Munten et al., 2021). Nonetheless the implementation of IPS2 could presents problems related to technological obsolescence. Systems' lifecycles which are longer than the technological lifecycles could translate in systems' inadequacy (Granholm & Grösser, 2017).

B. Opportunities

a) Extended responsibility

A characteristic of IPS2 which can be leveraged to achieve sustainability is the extended responsibility of suppliers. Suppliers of IPS2 are indeed more motivated to establish closed loop recycling management strategies (Pessôa & Becker, 2017).

Many opportunities for increasing the sustainability of IPS2 come from the management of the use phase of products. During the running phase there is the opportunity to satisfy customers' requirements with minimal resource consumption, thus lowering the environmental impact (Ding et al., 2017).

Thanks to the long-term responsibility, providers are motivated to offer services and activities to increase the offerings' value (Karni & Dror, 2014), both to increase the revenues streams and to extend the lifespan of products they are responsible for.

The use phase can and should be optimized through services, the IPS2 offerings should emphasize product longevity, create and expectation of continuous extension of system functionality through appropriate procedures (Karni & Dror, 2014). Activities such as maintenance, repairing, upgrade services and training, increase the value of the offering and aim at extending the product lifecycle (Granholm & Grösser, 2017).

Moreover, IPS2 imply increased relationships between providers and costumers. This element offers opportunities to increase the understanding of customers' needs and facilitate in providing the correct IPS2 solutions. The longer relationships preserve the usability of products, extending their lifecycle. (Pessôa & Becker, 2017)

IPS2 is a high enabler of remanufacturing activities, it influences provider to design products taking into consideration future remanufacturing activities of entire products and single parts (Guidat et al., 2014).

b) Digital Technologies

IPS2 solutions are often embedded with digital technologies which can be leveraged to increase the sustainability of the offering: sensors and data in IPS2 can increase the optimization of related activities, reducing their environmental impact. Data collected by the products can be leveraged to define the best characteristics of the integrated services (i.e., route definition for transportation activities) (Lindström et al., 2017). Moreover, the real-time collection of data allows the visibility of the operations' status (Lindström et al., 2017).

Manufacturing and repairing activities can be guided by data collected through sensors and qualitative data extrapolated from reports through text mining technologies (Mamrot et al., 2016). Digitalization, moreover, enables the collection of data related to the risk of failure. Manufacturers can leverage this information to identify the optimal timeframe in which to carry on maintenance activities (Schroeder et al., 2022). This approach offers better optimized maintenance and repair services, thus increasing sustainability (Mamrot et al., 2016).

The role of digital technologies is crucial also for the monitoring of the actual environmental impact of the solutions. The distributed manufacturing paradigm is appropriate for the integration of sustainability assessment, complementing sustainability thinking (Nagarajan et al., 2018). In (Bettoni et al., 2018; Landolfi et al., 2019) a manufacturing as a service (MAAS) system, through the implementation of digital twins, IoT and data, leverages an integrated tool for the implementation of LCA. The integrated LCA allows to monitor the environmental sustainability of the integrated offering. IPS2 with embedded digital technologies facilitate the collection of valuable data for sustainability assessment, proving and monitoring the sustainability of the solution.

MAAS's platforms enable also social benefits: new jobs ventures are created by linking innovation demand and supply (Bettoni et al., 2018).

V. Discussion

From the analysis of the literature, it is possible to observe that even though the topic of PSS's sustainability is recognized as relevant, few authors focus on its declination, specifically in relation to IPS2 configurations. Most paper analyze sustainability from the economic and environmental perspective, not studying the social impact of IPS2 configurations.

The authors identified main challenges to the achievement of sustainable impact and the main opportunities that can be leveraged. These characteristics have been used in the previous chapter to illustrate the findings of the literature review and are summarized in Figure 1.

Challenges	Opportunities
- Uncertainty and complexity - Trust between partners - Increased impact - Long system's lifecycle	- Extended responsibility - Digital technologies

Figure 1. Challenges and opportunities

Regarding the challenges, IPS2 have different characteristics from the traditional configurations, and they should be taken into consideration during the design and running phases of the integrated offering.

It is possible to observe that IPS2 are characterized by a higher degree of complexity and uncertainty than traditional offerings. IPS2 require the involvement of multiple actors and the offerings are composed by more resources, both tangible and intangible, which must be orchestrated in an effective way. In the path of transformation towards a IPS2 business model, uncertainties could prevent the achievement of positive environmental sustainability. An erroneous management of the uncertainties and complexities could bring to inefficiencies and diseconomies.

A crucial element of IPS2 are the relationships between actors, IPS2 require close relationships between the provider of the offering and customers. The extended responsibility of suppliers on their products translates in longer supplier-customer relationships. Moreover, many of the services integrated in the offering require the trust of customers, which are expected to communicate critical data to their suppliers. Not only there is the need to establish a close relationship between the stakeholders, but the IPS2 offering should be designed and communicated appropriately to build trust between suppliers and customers. Even though this challenge is crucial for the implementation of IPS2 services, few papers studies it.

The design of IPS2 should be done taking into consideration the environmental dimension. The proposal of IPS2 offering, which does not take into consideration possible rebound effects, could bring to increased environmental impact. The characteristics of the offering and the real impact of the new IPS2 configurations should be studied to avoid increased environmental impact, missing out the opportunities of this trend.

The final challenge that IPS2 may encounter is the extended life of the systems, that could become obsolescent if their lifecycles are longer than the technical ones. This could bring to worse environmental performances in the long run.

IPS2 present also unique elements that can be and should be leveraged by practitioners to increase the environmental sustainability of the offerings. IPS2 are characterized by extended responsibility of manufacturers over their products and increased relationships between suppliers and customers. The extended responsibility of suppliers translates into major opportunities to achieve environmental sustainability. Indeed, suppliers are motivated to increase the lifecycles of their products, at the same time they can extend them through services. The services offer both new revenues opportunities and extend the operative time of products. Services such as maintenance, repairing, training, the offering of optimal operating conditions can be leveraged both from an economical and environmental perspective. The role of the suppliers encompasses also EoL procedures: manufacturers are involved in activities to monitor the final phases of the products and are motivated to remanufacture, reuse, and recycle as much as possible the products.

A final, and major opportunity for sustainability, characterizing IPS2, is the role of digital technologies, which is crucial both for the implementation of the offering and for the achievement of environmental benefits. IPS2 are often characterized by a high number of sensors and technologies to capture of operative data. The data can be used to monitor the day-to-day operations as well as being applied to characterize the service offering. Data collected in IPS2 can be leveraged to carrying on the services of the integrated offering, such as maintenance and repairing activities. These activities have a double environmental sustainability role: they aim at increasing the lifespan of products, and the implementation of data allows the sustainable optimization of those activities. Moreover, the data collected by machines can be used to monitor the actual sustainability of the operations, giving visibility to their impact and highlighting when interventions to improve it may be required.

The current contributions offers both theoretical and practical implications. From a theoretical perspective it extrapolates and analyses the main barriers and challenges recognised by literature to the implementation of IPS2 to achieve social and environmental sustainability. From a practical perspective, this contribution offers to practitioners an analysis of the challenges that should be taken into consideration when designing and implementing IPS2 to achieve positive environmental impact. Moreover, it highlights which unique characteristics of IPS2 can be leveraged to reduce the environmental burdens of their business models.

VI. Conclusion

This paper focuses on the sustainability of IPS2 offerings. Current literature identifies PSS as a viable option to achieve environmental and social sustainability, nonetheless few studies propose researches on the role of IPS2 offering for sustainability. Through the implementation of a systematic literature review, the authors aimed at covering this gap. The paper offered an analysis of the main challenges and opportunities for the achievement of IPS2's sustainability. IPS2 is a viable path to achieve sustainable manufacturing, in particular thanks to the extended responsibility of suppliers over products and to the role of digital technologies, both for the implementation and characterization of services and for the monitoring of environmental performances. Nonetheless, many intrinsic characteristics of IPS2 could reduce the environmental benefits. IPS2 shows high level of uncertainty and complexity and require high level of trust between partners. Moreover, if not designed with sustainability as a goal, the impact of integrated solution could be higher than the traditional counterparts.

The study presents limitations that could be explored in future research. The first limitation is related to social sustainability. Only one of the analysed papers proposes considerations related to the impact of IPS2 on the social sustainability, further research could focus on this topic through empirical methodology and case studies. An additional limitation is related to the methodology selected; the literature review takes into consideration only papers which explicitly declare they are studying IPS2. This has been done in order to have a narrower industrial perspective. It is possible that paper studying PSS may study IPS2 without mentioning it explicitly, causing relevant papers to be excluded from the research. A final limitation is the theoretical approach of the research, the paper study the topics only from and academic perspective, considering the relevance of the topic for practitioners the same topic could be explored through interviews to practitioners and industrial case studies. These limitations could be overcome in future research.

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