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Product-Service Systems across Life Cycle

# Remanufacturing with Upgrade PSS for New Sustainable Business Models

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**Abstract**

Product Service Systems are indicated in literature as enablers toward a more sustainable and resource-efficient industry. In particular, the potential of Eco-efficient PSS to promote more sustainable industrial practices, such as re-use and re-manufacturing, has been discussed outlining the possible environmental advantages deriving from a more intense use of resources and emphasizing the economic benefits for producers as well. In recent years, together with barriers hindering the implementation of such strategies, authors started discussing also some 'rebound effects' that could limit the expected re-manufacturing environmental benefits, such as the obsolescence of re-manufactured products, especially in case of fast technology cycles. To overcome these criticalities and to target high-value customers segment, the concept of product upgrade in re-manufacturing has been introduced. Upgrade cycles would allow embedding technological innovation into products, to reach advanced environmental performances over time and to satisfy evolving customers' preferences. However, the concept of product re-manufacturing with upgrade has been treated mainly theoretically with limited evidence of industrial applications in PSS. Producers currently engaged in established remanufacturing practices are mainly big manufacturers of durable or long life-time products, in particular in the B2B sector, while only few pioneering cases of PSS offering product upgrade are cited in literature, mainly referring to B2C. To contribute to the progress of the state of the art and to move from theory to industrial application, this article takes a business model perspective for the implementation of remanufacturing with upgrade PSS. A coherent configuration value proposition, supply chain and reverse logistics, revenue model and ownership scheme is proposed, aiming at addressing the major criticalities and barriers encountered in the literature for the implementation of remanufacturing strategies. The producer will play a central role in the business model, since he has the knowledge and capability to conceive product's design and supply chains suited to perform remanufacturing and upgrade cycles. Potential benefits, and unsolved barriers to the implementation of the proposed business model are finally introduced in order to suggest future research directions.


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*Keywords:* Re-manufacturing; Upgrade; Business Model

## 1. Introduction

The increasing demand for raw materials and the growing concern in developed countries about industrial sustainability issues is raising many challenges in manufacturing industry, requested to compete on multiple fronts: to comply with environmental requirements set by the legislators, to compete for the resource supply and to satisfy the needs and preferences of markets, demanding higher performances of products a and services also in terms of environmental impact. To meet these emerging issues, in the last decades policy makers, the business community and academia embraced the new approach of "Industrial Product Service Systems" as a shift in the business perspective, aiming at fulfilling customers' needs through "*a marketable set of products and services*"[1]. Authors have focused, on one side, on the potential of this new combinations of products and services to create additional value for customers [2,3]; on the other side, they claimed the capability of PSS to minimize environmental impact of businesses [4,5]. Authors argue that the capability of PSS to lover environmental impacts of industrial activities lies in the producers' focus shifted, from selling products, to fulfilling needs. Therefore, the objective of maximizing physical product's sales is abandoned and the issues of resource preservation and their efficient use along


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products' life cycles become implicit objectives in producer's strategies. More sustainable practices, such as products life cycle extensions, closing material loops and minimizing emission, end-of-life optimized treatments, design for re-use and re-manufacturing of products, become strategic means for the product-service providers to increase their profitability.

## 2. Methodology and outline

In the following section, a critical review of the existing literature is presented, with the aim of summarizing the determinants of PSS environmental and economic impacts. The different configuration of such determinants and the associated effects on both environmental and economic indicators will be outlined, in order to derive means and strategies to improve such performances.

In Section 4, product upgrade cycles within remanufacturing strategies are presented as a strong value-creating asset, enabling, in a coherent business model formulation, sustainable and value oriented PSS implementations.

In section 5, a business model configuration for producers aiming at implementing Sustainable PSS is proposed in terms of coherent Value Proposition, Supply Chain configuration and Revenue Model. The proposed configuration aims to combine the sustainability and value enablers within the producer's business models, in a way that allows overcoming, or mitigating, implementation barriers or market unacceptance factors, and allowing both customers and suppliers to reach the desired values.

## 3. Benefits and barriers of Sustainable Industrial Product-Service Systems:

Starting from mid '90s the potential of Eco-efficient PSS to promote more sustainable industrial practices, such as re-use and re-manufacturing, was discussed outlining the possible environmental advantages deriving from a more intense use of resources and emphasizing as well the connected economic benefits for producers. In fact, functional sales and remanufacturing began to be considered as reciprocal enablers within producers strategies. Sundin and Bras, 2005 [6] claimed that *"products to be used for functional sales should be remanufactured"* and, vice versa, PSS formulas have the potential to improve remanufacturing performances, for example allowing a better control of assets during the use phase and enabling a stable sourcing back of the cores for remanufacturing.

However, despite the enthusiasm about Eco-efficient PSS, scholars expressed some concerns on their effective implementation success possibilities, uncovering barriers, disadvantages and possible drawbacks.

### *3.1. Environmental impacts determinants of PSS*

Determinants of the environmental impact of a PSS can be found in all its life cycle phases, from the inherent design of the product-service, to the use phase behavior of customers and suppliers, till the products end-of-life treatment strategies. It cannot be assumed that a PSS is environmentally and economically sustainable by definition: from the extensive review upon resource-efficient PSS operated by Tukker, 2013[7], it emerges that the determinants of the environmental impact of a PSS depend on:

- the PSS Value Core:
  referring to the most common PSS classification, distinguishing between product-oriented, use-oriented and result-oriented PSS, Tukker,2004 [8], proposes a ranking of these categories in terms of environmental potential of the systems. He argues that the more the value core of the PSS is undocked from the physical product and resides on the obtained result, the more the producer is incentivized to find more material-efficient ways to fulfill customers' needs. Result-oriented PSS are considered to provide the greater incentive to minimize materials consumption, but are the ones which require the most radical change in producers and customers relationships.
- the Utilization Patterns:
  such as products sharing and pooling, deeply influence the use intensity of products, and therefore determine a more efficient use of resources. To fulfill with single assets multiple customers' needs, can improve the producers' specialization, scale economies and efficiency [9]. Moreover, a faster products turnover, due to more intense usage, could lead to faster innovation, introducing product's improvements in terms of energy and materials consumption [10].
- the Ownership scheme:
  authors argue that the customer's behavior is deeply influenced by the ownership of the products, and that a non-ownership scheme could lead to less careful utilizations behaviors, causing a quicker deterioration of the products [11], hindering life-time optimization strategies. On the contrary, producers retaining product ownership would pay higher attention to products preservation and would implement practices such as design for durability, reuse and re-manufacturing.
- Products Life Cycle Strategies:
  when providing a function instead of a product the suppliers internalize the performances of in-use products and will manage their life cycle in order to increase revenues [12] for example enabling consecutive use-cycles by means of re-manufacturing activities and re-use patterns for suitable markets, with the intent of gaining the maximum value from retired objects. On the contrary, if the life cycle strategy of a PSS foresees single products use-cycles, manufacturers might still have the incentive to create 'built-in obsolescence' in order to sell replacement products sooner [13].

- Revenue schemes:
  sale, leasing, renting, pay per unit of use, pay per functional result, all these revenue schemes are able to stimulate different consumers and producers behaviors, determining peculiar revenue maximization strategies. As for the PSS classification categories Tukker, 2004 [8], propose a ranking of the cited schemes in terms of possible environmental performances. While traditional product sale has demonstrated ineffective to provide producers with the adequate incentive for more environmental practices, leasing and renting still score quite low in their environmental potentials, mainly due to the possible careless users' behaviors and additional provisions needed by the producers to restore and preserve objects' attributes. Pay per use and per result are investigated as promising schemes, since the position in the value chain retained by the producer improves in terms of control over products life cycle, efficiency and freedom to innovate.

### *3.2. Economic impacts determinants of PSS*

The emphasis on economic implications of sustainable PSS has acquired importance in recent years. It is argued that, in competitive markets, the offer of integrated products-services solutions could allow the producers to improve their competitive position, establishing more sustained relationships with the customers, increasing efficiency, reliability, or utility for the user, and consequently market share and profits [14].

In its review, Xing, 2013 [12], argues that it is almost unanimous in the existent PSS literature that integrating product and services contributes to value creation on the supplier side, by facilitating the multiple utilization of products, and enhancing performances and user experience on customers side, with a set of value-adding services, such as installation, maintenance, upgrade, and take back.

In order to determine the economic value of a PSS offer, authors considered essential, to analyze added value on the customer's side, whose determinants con be summarized as follows:

- Functional and aesthetic fitness:
  normally reduces over time, due to objects obsolescence and the introduction of innovative technologies and designs. For a product in PSS, the more the level of functional fitness is preserved, by replacing old components with newer, better ones or adding new functional modules for upgrade, the more the value perceived by customers' increases, together with the potential to serve for longer periods [12]. The aesthetic and "fashionable" issue is not of secondary importance, especially in B2C markets. The willingness for up-to-date design may create uncertainty about market acceptance of those products whose functional life cycles have been extended over time [16].
- Affordability:
  Bankole et al., 2012 [17], examined the definition of customer affordability as "the provision of products and services that are affordable to the customer given their budget allocation". Customers will compare resources in terms of time and money needed to have access to the product-service compared with the traditional product-based solution.
- Intangible added value:
  relates to customer's satisfaction factors such as sense of control, ease of access and status recognition. In this respect the risk for PSS, particularly in the B2C area, is to be perceived as less valuable than the competing product solutions, in particular in relation with the ownership issue. Consumers appreciate ownership and control, new and "fashionable" products, and availability and easy access to the product [10], all factors to be specifically addressed within new PSS business models, in order to limit the perception of the customers of being putted under control and of losing their freedom.

### *3.3. Barriers and drawbacks of Sustainable PSS*

A new set of assets and competences are required in order to implement such product-service integrated strategies. Zharing et al., 2001 [9], emphasized the need of new accurate accounting systems in order to monitor the more sophisticated costs and revenue streams rising from the new revenue models and services related activities. In fact, the complexity of financial streams implies distributed payment over time but leaves the producers in charge of initial capital investments and operational expenses during the entire assets' life cycles, therefore it is cited as a critical barrier. This issue is directly connected with the risk to provide a service for a long period, at a predetermined price, requiring high forecast capability over assets performances during obsolescence and a continuous understanding of evolving customer's needs and behaviors [18]. Moreover, assets investment needs, capital availability, operating costs together with networked production systems transaction costs [15] are the major factors cited as determinants of the economic viability of PSS business models.

Issues of organizational changes for the transition to a servitized operational strategy, knowledge management and critical competencies acquisition, company strategic fit and integration have been raised [19], arguing that the costs of the transition from product-oriented to PSS-oriented businesses could be prohibitive for some firms.

On side of organizational factors, important barriers to be overcame refer to the logistic infrastructures needed to provide services and manage physical assets over their life-cycles. PSS supply chains are figured as collaborative networks, where partners exchange information and materials more intensively than in traditional supply chains, thanks to aligned incentives and balanced benefits [20]. Configuring such supply chains is a challenge of primary importance, in particular for PSS involving multiple products' life-cycles. White et al., 2003 [21], described the main challenges connected with all the reverse logistic and re-manufacturing stages for products under rapid obsolescence, such as electronics and computers.

The PSS provider aiming at implementing a multiple life-cycle strategy of its assets is called to manage and overcome the information asymmetries about returned product conditions, which heavily hinder the efficiency of re-manufacturing processes, take care of the reverse collection and transportation system costs and manage the risk associated with the uncertain economic value of recovered products and components.

Focusing on eco-efficient PSS, literature started to warn about their possible rebound effects and drawbacks, questioning the expected re-use and re-manufacturing PSS environmental benefits and market-related economic value. Remanufacturing-based PSS, aimed at giving a second life to parts and components to avoid new resources consumption and decrease waste, face important limitations in terms of generational difference, which, as defined by Kwak, 2013 [22], "*is a relative measure that indicates, in terms of the technology, how obsolete a part is compared to a current cutting-edge part*". When novel products generations appears on the market, they generally offer lower environmental impacts compared to old products, as well as better performances, more advanced functionalities and updated aesthetics, resulting consequently more attractive for customers. A market competition between re-manufactured and novel products appears to be hardly sustainable.

For these reasons, generally, re-manufacturing business models address less demanding users segments that can accept non state-of-the art products, like for example emerging countries markets, non-profit organizations or second-hand markets [23]. Authors warned at the risk of "losing the innovation battle" while implementing multiple life-cycle strategies on high value markets [15]. A possible strategy to win this battle is indicated in "products' life-cycle improvement", intending the ability to introduce technological innovation, functionalities and performances enhancement and updated aesthetics over time.

## 4. The introduction of product Up-grade in Re-manufacturing

To meet the challenge of fast technology evolution in Re-manufacturing PSS, the concept of product upgrade has been introduced as a promising solution to traditionally re-manufactured products' obsolescence. Conventional products are often disposed due to functional obsolescence before the end of their physical life, even if they have both a residual unexploited physical life and economic value [24].

Remanufacturing with upgrade would aim to extend products value life, enabling the introduction of technological innovation into remanufactured products in order to guarantee advanced environmental performances over time and to satisfy evolving customers' preferences at the same time, preserving as much as possible the physical resources employed in the process. Thus, re-manufacturing with upgrade would solve the intrinsic contradiction between environmental and economic issues of Sustainable PSS. Upgradable products must be, by definition, robust against future uncertainties regarding technological development and market movements. Product upgrade is envisioned as a pro-active approach [25] where product architectures, functionalities, and upgrade plans are iteratively addressed in response of technological innovation and the evolution of value determinants for customers.

In recent years some authors addressed the upgrade approach, in terms of products design support methods [26,27]: in order to create robust upgradable products, modularity, standardization, compatibility and interoperability are advocated as key upgrade-enabling design features. Upgrade plans optimization tools [22,28] have been also proposed to cope with the prediction of products obsolescence and future trends such as technological development and market movements, or propose iterative and adaptive design approaches [29]. Decision support systems [30,31] have finally addressed the issues of products upgradability evaluation, part upgrade choices, risk management and upgrade scenario simulations.

Despite academic efforts, the evidence of industrial application of "Remanufacturing with Upgrade PSS" is really scarce. Producers currently engaged in established traditional re-manufacturing practices are mainly big manufacturers of durable or long-life cycle electronics or mechanical goods, addressing in particular the B2B sectors. Some examples are Caterpillar for engines, Fuji Xerox for photocopiers [32], Electrolux for washing machines, Ricoh for printers –also offering software upgrades– [33]. In most cases the re-manufacturing business is approached as a residual activity addressing second hand markets, or offering a re-manufactured products line at more convenient prices. In some cases, it can be found as an experimental attempt not very well integrated in the company strategy, still mainly anchored to traditional product sales business models.

A rare example of industrially-implemented Remanufacturing with upgrade PSS is the Bundles washing machines "pay-per-wash" experiment in the Netherlands. A washing machine connected via internet to a monitoring device is installed to customers' homes and, following the overview of the monthly usage, a periodical fee is requested [33]. Although the household appliance remains ownership of the service provider, users maintain all ease of access of a domestic device, taking advantage of the avoided initial expense. Moreover customers are provided with installation and take back services, together with maintenance and retrofitting of the appliance, currently a Miele machine, chosen for the employment of 100% reusable or recycled materials. In the contractual terms Bundles has posed particular attention to the customer's sense of control, by making terminating the contract as easy as possible. Due to the initial success of the business model, the company is planning to realize a new concept of washing machines, specifically designed for the purpose, with enhanced re-manufacturing and upgrade possibilities and monitoring and connectivity improvements [33].

Due to the discussed complexity and risks associated with the industrial implementation of Remanufacturing with

Upgrade PSS, as well as to its novelty and currently rare industrial application, in the following paragraph a business model for Remanufacturing with Upgrade PSS is proposed as a reference for companies.

## 5. Sustainable PSS Business Model Configuration

This Section proposes a coherent business model configuration in terms of Value Proposition, Supply Chain and Revenue Model for the implementation of Re-manufacturing with Upgrade PSS. Such a configuration combines the economic and sustainability enablers highlighted in the previous literature, in order to mitigate eventual rebound effects and enhance value for both customers and PSS suppliers.

### *5.1. Value proposition*

As highlighted previously, in a competitive value offer, customers have to be granted access, at sustainable conditions, to always up-to-date products, able to perform advanced functionalities with leading performances. To deliver such offer, a set of value-added services should be implemented by the supplier to accompany the physical assets along the life-cycle, such as:

- Product periodic take back and upgrade:
  by providing a periodical upgrade service through remanufacturing, the producer would be able to guarantee the continuous monitoring and restoring of products, with the possibility to embed technological or aesthetic improvements, customization features on request or new functionalities, thus maintaining always high satisfaction of customers, prolonging both physical and value life of products.
- Installation and eventual training services:
  to support product up-grade schemes, the producers should minimize the discomfort associated to the absence of the product at the customers' side for a period of time and avoid added customer's efforts in take back and re-installation activities, ensuring the service continuity and accessibility to customers. Producers should also periodically train customers on the upgraded products functionalities.

### *5.2. Supply Chain*

In order to deliver such a value proposition, the producer should provide a business infrastructure able to manage the processes for the manufacturing of products, the remanufacturing and upgrading operations and the logistic network for the take back and delivery activities. To implement such infrastructures the producer should manage a set of key resources:

- Technological:
  key enabling technologies, supporting the producer's value generating activities, would need to guarantee efficient manufacturing and re-manufacturing of products, with assembly/disassembly automated processes, assessment and testing technologies and product-embedded monitoring and connectivity systems. Enabling technologies are represented by flexible, adaptable and reconfigurable automated systems, robust against products and components variability in terms of technological generation, shapes, dimensions and conditions. Scalable manufacturing systems are required in order to adapt to the variable production capacity requirements, deriving from cyclic products reworking.
- Informative and knowledge:
  to successfully implement remanufacturing/upgrade activities, proper product design and upgrade plans optimization methods must be mastered and applied by the producers. Once delivered on the market, it would be necessary to continuously collect information about products usage and conditions, components failure and obsolescence rates, users behaviors and preferences, in order to predict and manage products performances along their life cycles in relation both to internal conditions and to the external perception of value by customers.
- Logistics infrastructure:
  one of the major issues impacting re-manufacturing strategies is in the difficulty of cores take-back. The timing and quantity of product returns is dependent on factors such as the mean product lifetime, rate of technical innovation, and failure rate of components. The periodical upgrade as a service strategy and the application of upgrade plans, is able to mitigate such uncertainty effects due to a prior forecast effort and the pre-determination of products' returns from customers. Nevertheless, products withdrawal and return to customers generate a proliferation of physical flows between producer's facilities and customers to be managed. Optimization methods in this field are generally location-allocation models, allowing companies to determine the optimal number and location of facilities and transportation methods.

### *5.3. Revenue Model*

In these business models the position of the producer is crucial, since he has the knowledge and capability to conceive product's design and supply chains suited to perform remanufacturing and upgrade cycles. In order to fully internalize the benefits deriving from design efforts and responsibility over the products' life-cycles, the adopted revenue model should guarantee the producer to collect cores in order to offer the promised service. Revenue schemes implying retained products ownership of the supplier are consequently suitable. For example, the customer might pay a periodic fee ("pay per use" or "pay per part"), which could also lower investment barriers for customers. Given the long-time relationship established with the customers, distributed payments schemes represent a win-win situation for producers and customers, both taking advantage form the overall enhanced resource-efficiency of the manufacturing system (components life cycle extension, reuse, re-manufacturing, optimized end-of-life treatments).

## Conclusions

This paper proposes a new business model for the implementation of Re-manufacturing with Upgrade PSS. It implies a radical discontinuity with the past since it generates added value for customers and new consumption behaviors, enabled by the capability to recover products' residual value while upgrading their performance at the same time. This new business models is far from being the state of the art and poses considerable challenges to companies. Even if adopted by some manufacturers offering re-manufactured products lines, re-manufacturing practices are not yet widely diffused as an explicit product life-cycle strategy in the industrial sector. Product-service value propositions offering product upgrade cycles within durable customers-suppliers relationships are even more rare in practice. The development of new enabling technologies in the fields of automated disassembly, flexible man-robot cooperative tasks configurations, easy reconfigurable and modular (re)manufacturing systems design, monitoring and diagnosis systems development are critical support assets for these PSS. Products should be re-designed in order to be remanufactured and upgraded in the future. Further studies measuring the economic and environmental sustainability of new manufacturing and de-manufacturing processes and supply chains are fundamental for the validation and promotion of the new business models by industrial communities. Finally, also customers' and manufacturers' culture should evolve in order to accept new production and consumption patterns.

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