Cascade Utilization During the End-of-Life of Product Service Systems: Synergies and Challenges

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Abstract

The circular economy concept is receiving increasing attention from academia and businesses as a conceivable means to decouple economic growth from material consumption. Product Service Systems (PSS), primarily due to their sustainability potential, have been identified as a promising lever that can facilitate the transition towards a circular economy. However, a product may not be more resource efficient or have reduced environmental impacts just because it is marketed through one of the various PSS business models. In this regard, the comprehensive End-of-Life (EOL) management of PSS can play a crucial role by maximizing the utilization of a product's remaining value. In this paper, we consider the applicability of the cascade use methodology proposed by Kalverkamp et al. [15] in the context of PSS. Additionally, we explore the possible synergies and associated challenges between PSS business models and cascade utilization.

1 Introduction

Rapid technological advancement, changing consumer preferences and increasing market competition prompt manufacturing companies to introduce a variety of often reduced lifespan products at a cheaper price. Consequently, a majority of manufacturers is trying to increase their profits based on sales volume and overall cost reduction. However, because of innovation through new knowledge, changes in consumers' perceived needs and excessive costs of repair or maintenance, these products quickly become obsolete [1] even before the end of their actual physical lifetime or economic value [2]. The current socioeconomic system is primarily based on a linear production and consumption model following a 'take-make-use-dispose' philosophy. This only elevates the environmental and economic challenges caused by inefficient use of scarce resources.

The concern about this growing environmental load related to economic growth has prompted increased interest in alternative ways of achieving more sustainable economic models through enhanced resource efficiency. In this context, the circular economy concept is receiving increasing attention from academia and businesses as a conceivable means to decouple economic growth from material consumption [3]. Unlike linear production and consumption models, the circular economy promotes greater resource productivity by reducing waste and use of virgin materials through reuse, remanufacturing, and recycling of End-of-Life (EOL) products [4-6]. However, from an economic prospective, circular business models need to assume more business risks compared to linear business models. This is primarily due to the complexity associated with reverse supply chains and the uncertain economic value of EOL products [7].

In this regard, Product-Service Systems (PSS) have been widely recognized as a promising lever that can support and facilitate the transition towards a circular economy [4, 6, 8-9]. The PSS business model, in which the use or the function of a product is sold instead of the product's ownership, can mitigate the provider's risk to maintain circularity of EOL products, components, or materials. One of the main reasons is that in case of such PSS, providers have access and better control of the products as well as information regarding the condition, quantity and timing of the returns [10]. Additionally, companies that retain ownership of a product are responsible for the whole lifecycle of their product [11] and thus will have an intrinsic motivation to (i) prolong the useful life span of their products, (ii) maximize utilization, (iii) ensure energy and material efficiency, as well as (iv) reuse products, components, and materials as much as possible after the end of the product's life [9, 12-14].

However, a product may not be more resource efficient [9] or have reduced environmental impacts [14] just because it is marketed through one of the different PSS business models. In this respect, the comprehensive EOL management of PSS that will help to maximize the utilization of product's remaining value can play a crucial role. The cascade use methodology, which has been widely utilized in the biomass domain, offers a broader perspective on the EOL [15]. Recently, Kalverkamp et al. applied this methodology in the context of products that are not marketed through renting or sharing (i.e., PSS) business models [15]. In this paper, we consider the applicability of the cascade use methodology in the context of PSS, while exploring possible synergies and associated challenges between PSS business models and cascade utilization.

The remainder of the paper is structured as follows. In the next section, key concepts for the later discussion are presented in the form of an overview of circular economy, PSS and cascade use. The third section summarizes the cascade use methodology proposed by Kalverkamp et al. [15] and considers its applicability in the context of PSS. The

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fourth section sheds light on the potential synergies and associated challenges between PSS business models and cascade utilization. The final section summarizes and concludes the paper and provides future research directions.

2 Key Concepts

In this section, key concepts for the later discussion are presented in the form of an overview of circular economy, PSS and cascade use.

2.1 Circular Economy

The circular economy concept is attracting significant attention from researchers, industry and policy makers. In the literature, the most common and widely accepted definition of circular economy is given by the Ellen MacArthur Foundation [6], which defines circular economy as a "system restorative and regenerative by design, which aims to maintain products, components and materials at their highest utility and value". The Ellen MacArthur Foundation has also identified the following three circular economy value drivers: (i) pursuing resource efficiency, (ii) extending the lifespan of products and (iii) closing the material loop. The circular economy puts forward the idea of restoration and circularity in order to decouple the environmental burden from economic growth by enabling multiple closed-loop cycles of reuse, remanufacturing, and recycling [23-24]. The circular economy business model has a strong connection with PSS due to the fact that the responsibility related to the management of EOL product's lifecycles shifts to the PSS provider. This shift of responsibility from a private person (user) to a professional entity (PSS provider) supports the sustainable management of closed-loop industrial systems where materials are recollected, reused, remanufactured, and recycled [25].

2.2 Product Service Systems (PSS)

PSS can be understood as a special case of servitization - a concept introduced by Vandermerwe and Rada in 1988 [16], long before PSS were introduced. Servitization describes the phenomenon of manufacturing firms developing value propositions by incorporating additional services in order to attain a competitive edge in the market [17]. Servitization and PSS, both describe the same concept (i.e., "a marketable set of products and services" [1]) but PSS usually involves the sustainability context in addition to the somewhat 'economic only' context of servitization. In 1999, Goedkoop et al. [18] introduced the term PSS and defined it as "system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models". A solution composed of physical products and related services may be harder to replicate for a competitor, compared to solely product and process-based manufacturing [19]. Additionally, integrated services mean more satisfactory experience for customers and generally increased revenue for the manufacturers [20].
PSS business models can be categorized into the following three distinct types [17, 21]:

- *Product oriented business models:* The primary purpose of this business model is to provide tangible value to the customer. The ownership of the product is transferred to the customer, while the PSS provider sells additional services in the form of maintenance, upgrades, or EOL take-back.
- *Use oriented business models:* In this business model, the PSS provider sells the use or availability of a product that is not owned by the customer. Examples of this type are product leasing or sharing.
- *Result oriented business models:* In this business model, the PSS provider sells a result or capability of a product and not ownership. For example, instead of selling a printer to a customer, the company can sell the result, such as document management capability.

This paper mainly focuses on the use and result oriented PSS business models. A business strategy built around these business models establishes a value proposition in which manufacturers retain the product ownership and are responsible for its functionality, maintenance, upgrade, and EOL management. This transfer of the responsibility to manufacturer creates an incentive for them to design best possible products in terms of superior functionality, reduced operational (i.e., less consumables inputs) and maintenance cost, and better reusability, re-manufacturability, and recyclability [22]. As a result, PSS may prove to be a more resource efficient and effective solution with less environmental impact compared to conventional product-oriented solutions.

2.3 Cascade Use

The cascade use methodology originates from the forestry sector and has been widely utilized in the biomass domain. Cascade use can be defined as the efficient utilization of resources by using a certain resource sequentially for different purposes [26-27]. The objective is to first exploit the products, components, and materials on higher cascade levels for a longer period of time, before using them as an energy source. In the case of products, adopting a cascade use means pre-planning and designing the route of the EOL products from one product or component to another [28], for example, using EOL electric vehicle batteries in stationary applications before recycling the materials. Another common example from the biomass domain is the use of solid timber in higher value products with large dimensions, instead of chipping it or using it as fuel for energy [29].

Circular economy and cascading utilization have many parallels and similarities [30] in that both strategies promise to increase resource efficiency by a circular management and multiple uses of resources [31]. However, cascade use primarily focuses on the utilization possibilities (e.g., reuse, remanufacture and recycling) of a particular resource, while circular economy provides a more holistic approach [30].

3 Cascade Methodology and its Applicability in the Context of PSS

In the next section, we first summarize the cascade use methodology proposed by Kalverkamp et al. [15], and then consider the applicability of this methodology in the context of PSS.

3.1 Cascade Use Methodology

The cascade use methodology aims to highlight and integrate the complexity of end-of-life options into the management of product lifecycles. The cascade use methodology shows how products and eventually materials cascade through reuse and recycling to recovery (ideally avoiding landfill). Originally, the concept of cascade use stems from the biomass domain where it represents how renewable resources such as wood, i.e. wood fiber, cascade through consecutive processes of use, reuse, and recycling before being treated as an energy source [32]. The term "cascade" or "cascade use" (and similar versions) is also used outside the biomass domain, for example in the context of lifecycle management, reuse, and product returns [33].

For the cascade use methodology, the biomass-domain "cascade" serves as a blueprint in combination with the steps 'reuse', 'recycle' and 'recovery'. These steps are derived from the waste management hierarchy [34]. Fig. 1 shows the cascade use methodology and depicts clearly the increasing complexity and variety of end-of-life options at the levels reuse, recycle, and recovery. This cascade perspective neglects the possibility that products and materials can as well move from a lower to a higher cascade level. An example how this might be facilitated is through an upcycling or reuse process, transforming a discarded product into another (new) product. In such case, the product/material flow exits the cascade and enters another cascade, representing the end-of-life of this new product. Products and materials can also remain at the same cascade level through iterations of reuse (e.g., remanufacturing) or recycling (e.g., up-/down-cycling). This cascade does not consider landfill as landfill does not contribute to circularity [34].

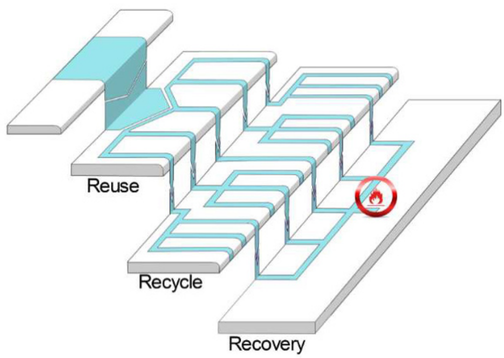

Figure 1. Cascade Use Methodology [15]

Although the cascade perspective influences the product lifecycle from its beginning, the reality at the product's end-of-life may not fit the planned lifecycle even if circular business models such as PSS or closed-loop supply chains were used to manage the product lifecycle. At some point, products may leave the system "unscheduled". For example, when third-parties take advantage of products offered to the "outside system". The latter case is most likely to occur in systems associated with a transfer of ownership (rather than PSS). However, even products used in a PSS setup may eventually end up with another owner. At this point, the end-of-life-options increase and so does the complexity of managing the EOL. The visualization of different cascades fosters alternative end-of-life solutions, in supporting decision makers to identify economic and environmental potential in the different 'streams' of the cascade by integrating market realities (e.g. trade with used products) of changing end-of-life options. The cascade use methodology acknowledges this complexity and recognizes that one supply chain owner can hardly manage all potential end-of-life scenarios.

Kalverkamp et al. [15] introduced a case study on the cascade use of tires (Fig. 2). It was found that after their first use, tires are reused without any alteration in another market, which tolerates a lower tread depth of tires. In the next cascade level, tires with too low tread depth are retreaded as a remanufacturing operation. Before using tires in the energy recovery cascade level, the tires are recycled into new products such as shoe soles or artificial turfs.

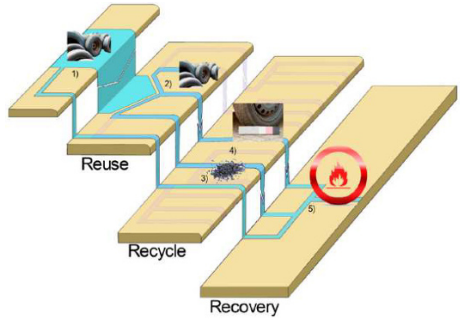

Figure 2. Cascade Use of Tires [15]

In a second case study, the authors outlined how a product component moves through the different cascade levels while not being managed in a typical closed-loop supply chain scenario. They identify third parties taking advantage of discarded suspension control arms for remanufacturing purposes. Their case shows that the third party closes the component loop and improves the environmental impact of the component through an extended component lifetime. The related process innovation for the remanufacturing of this component highlights that third parties, not being part of a closed-loop supply chain or a PSS, can contribute significantly to the sustainability of products and components. This marks one of the potential challenges of PSS where due to different reasons the product producer may be no longer interested in a product life extension although such could still provide environmental benefits.

3.2 Applicability of the Proposed Methodology in the Context of PSS

Instead of assuming integrated reverse flows from the EOL towards predefined reuse and recycling processes, the proposed methodology takes into consideration that highly integrated, totally market oriented and intermediate organizational types coexist. As a result, it includes both open and closed-loop supply chain perspectives to reflect the broad variety and complexity of different EOL options.
On the other hand, use/result oriented PSS by definition form some kind of closed-loop supply chain as the providers retain ownership of the PSS. The closed-loops are especially prevalent at the reuse and remanufacturing levels. However, at the recycling and recovery levels, a closed-loop setting may not be a viable option for a majority of the PSS providers. For example, the lack of economies of scale may prevent a washing machine provider to recycle all the materials of an obsolete washing machine when building a new one. For this reason, PSS providers may feel more comfortable in an open loop setting at the recycling and recovery levels.
In this regard, the proposed methodology could be a good fit for PSS, given their need for both open and closed-loop supply chain perspectives. Therefore, we propose to consider the cascade use methodology in the comprehensive EOL management of PSS to support the transition towards a circular economy.

4 Synergies and Challenges of PSS Business Models and Cascade Utilization

The authors of the proposed methodology identified policy, new technology (e.g., for remanufacturing or recycling), business models and raw material prices as the possible influencing factors that affect the mass flows within different cascades. However, the authors do not consider the aspect that there could be several factors that may influence the eco-efficiency of a particular cascade level. For example, there are several factors that influence the eco-efficiency [35] of remanufacturing, such as product design, build quality and information regarding the condition, quantity, and timing of the returns. Similarly, different business models with their distinct characteristics can be understood as one of such influencing factors that can play an important role in determining the efficiency within a cascade level. This observation calls for an exploration of the possible synergies and associated challenges between PSS business models and cascade utilization.

4.1 Possible Synergies

Compared to traditional manufacturers who rely on product sales, PSS providers have better capabilities (systematic recovery, product condition and usage data, technical knowledge, investment potential, market for recovered products etc.) and economic incentives to ensure the optimal reuse and remanufacture of EOL products. Consequently, a product marketed through a PSS business model may have a better chance to be utilized at the higher cascade levels such as reuse and remanufacture due to readily available information throughout the supply chain. Retained ownership of the products, closer customer relations and the information regarding product location help PSS providers with systematic recovery through a better organization of the collection (for remanufacture/recycle) and reallocation (for reuse) activities during EOL or when the subscription ends [7, 23]. As the EOL products originate from various sources and different working conditions, they do not show uniform quality conditions, which results in unique remanufacturing needs [36]. However, due to advances in information technology, PSS providers can gather large amounts of usage data throughout the lifecycle and track the condition of the products and components in real-time, allowing for less uncertainty and better performance of remanufacturing activities [23]. Furthermore, in order to restore a product to original or better condition, remanufacturing requires considerable expertise and knowledge of the product that is generally readily available to PSS providers [7, 37]. Another challenge for remanufactured or second-hand products is that their price needs to be adjusted in order to attract customers. However, in a PSS setting, the acceptance and demand for those products is significantly improved as the customers only use the product without having its ownership transferred (i.e., paying for it) [38].

Product design can also play a crucial role to ensure higher levels of cascading use such as reuse, remanufacturing and recycling while delaying final sinks such as energy recovery or landfill. Thinking in the perspective of cascade use will help to appropriately consider and reflect the EOL requirements during the design phase. Certain design decisions taken at the Begin-Of-Life (BOL) stage can have major implications in the management of EOL products. For example, it can be very inefficient to manage an EOL product if its design makes it difficult to disassemble in order to remove hazardous substances [39]. On the other side, the design can reflect the future need for easy disassembly, e.g., by using threaded fasteners instead of epoxies, however, this is often associated with an increase in cost. Since the PSS providers retain the ownership of the product, the entire lifecycle management of the product becomes their responsibility and they tend to focus more on the Total Cost of Ownership (TCO) instead of mainly focusing on design and manufacturing associated cost. Therefore, PSS providers have several incentives to design more durable and flexible products while keeping different eco-design criteria, such as design for disassembly, remanufacturing, and recycling, in mind [40]. Moreover, designing for technological cycle [41] enables alternative revenue models that create value from waste [42], for example, ‘cradle-to-cradle’ [43] – where raw materials are chosen based on their recyclability nature; and ‘industrial symbiosis’ [44], where by-products from one process become feedstock for another process.

4.2 Associated Challenges

One of the challenges of maintaining a closed-loop supply chain within PSS business models is that it may limit the innovation potential of third party remanufacturers, who can often lead the way towards the remanufacturing of new parts that are not being remanufactured by the OEMs [15]. In some cases, third party remanufacturers can even create a remanufactured component that performs better than the equivalent new part manufactured by the OEM. For example, a third-party remanufacturer claims to have overcome the common failure of a throttle body by improving its design [45]. These kind of solutions bring economic gains for both the remanufacturer (profit) and customer (lower cost) while contributing towards the environment by delaying material recycling [15]. However, in a closed-loop setting the flow of EOL products and components may not reach such third-party remanufacturers, resulting in a loss of innovation opportunity.

Due to the complexity at the EOL, it is very difficult for PSS providers to manage all available EOL options on their own. Consequently, several stakeholders govern the decision on product design and EOL recovery option. There are several factors that affect these decisions; these factors are related to engineering, business, environmental, and societal aspects [46]. However, there can be conflict between these factors, which may result in varying prospective between stakeholders. For example, material recycler’s interest in pure and easy to recycle material may not coincide with PSS provider’s interest in composite light weight material [46].

Another drawback specific to PSS business models is that the users may not use the PSS in the recommended way since they do not actually own the PSS. This may adversely affect the useful lifespan and thus the underlying objective of cascade use. The cost of maintaining reverse logistics can be another important concern for the PSS providers. Even when a particular remanufacturing or recycling operation is technically feasible, the costs of recovery operations must be less than the recovered value in order to make remanufacturing or recycling economically attractive for PSS providers [47].

5 Conclusions and Future Research

This paper investigated the applicability of the cascade use methodology in the context of PSS. It further explored possible synergies and associated challenges related to PSS business models and cascade utilization. Cascade use methodology includes both open and closed-loop supply chain perspectives to reflect the broad variety and complexity of different EOL options. Thinking in the perspective of cascades will enable PSS providers to consider a broad variety of EOL alternatives in addition to the originally planned options in the closed-loop setting. Consequently, the environmental and economic benefits of the PSS business models may go beyond the initially designed lifecycles. PSS have a better chance to be utilized at the higher cascade levels due to readily available lifecycle information. Furthermore, PSS providers have more incentives compared to traditional manufacturers to design a product with the objective of retaining them at higher cascade levels for a longer time.

Future research should concentrate on how PSS providers can go beyond their closed-loop supply chain setting and incorporate solutions offered by third party remanufacturers and third markets. Furthermore, future research should develop a method that will consider the collective interests of all stakeholders when designing a PSS and deciding on EOL recovery options in order to transcend the boundaries of individual stakeholders. A methodology to assess the cascading degree within a PSS supply chain can play an important role in proper implementation of the circular economy. Lastly, a wide implementation of PSS business models and therefore a transition towards the circular economy will require simultaneous support from manufacturers, customers, policy makers, lawyers, and regulatory institutions.

6 Zusammenfassung

Das Konzept der Kreislaufwirtschaft steht als mögliche Maßnahme zur Entkopplung des wirtschaftlichen Wachstums von einem steigenden Materialverbrauch zunehmend im Fokus von Wissenschaft und Wirtschaft. Aufgrund ihrer Nachhaltigkeitspotenziale wird Produkt-Service-Systemen (PSS) eine vielversprechende Rolle bei der Umstellung zu einer Kreislaufwirtschaft zugesprochen. Allein die Tatsache, dass ein Produkt als Teil eines der vielfältigen PSS Geschäftsmodelle vermarktet wird, bedeutet jedoch nicht dass es als ressourceneffizient angesehen werden kann oder geringere Umweltwirkungen verursacht. Das umfassende End-of-Life (EOL) Management von PSS kann in diesem Sinne eine wesentliche Rolle spielen, indem es die Ausnutzung des verbleibenden Produktwerts maximiert. In diesem Beitrag wird untersucht, inwiefern sich das von Kalverkamp et al. [15] vorgeschlagene Konzept der Kaskadennutzung auf PSS übertragen lässt. Zudem werden mögliche Synergien und Herausforderungen zwischen PSS Geschäftsmodellen und Kaskadennutzung betrachtet.

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