CHALLENGES AND RESEARCH ISSUES FOR REMANUFACTURING IN PAAS FROM THEORY TO INDUSTRY PERSPECTIVE

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Abstract
Product-as-a-service (PaaS) is an emerging business model, that supports upscaling of the circular economy in the industries with producer's extended responsibility. In the PaaS models, the ownership of products stays with a manufacturer, and the functionality of a product is offered to customers for a limited period of time. The successful implementation of PaaS requires multiple uses of products across more than one life cycle. Remanufacturing is vital to bring the return product to conditions that make it attractive to customers in the next PaaS offering. The PaaS business model can make many of the earlier remanufacturing research issues irrelevant (e.g., the uncertainty of incoming cores), and it may enable research to focus on a limited set of issues that are manageable in practice. The purpose of this paper is to present a summary of the literature review on the challenges of remanufacturing in PaaS (product as a service) settings. We identify and assess in a structured way the main challenges that are crucial for upscaling remanufacturing in PaaS settings. We combine the findings of the literature review with the insights of industrial cases.

Keywords:
Remanufacturing, value retention process (VRP), circular business model, electrical and electronic equipment

1 INTRODUCTION

Electrical and electronic equipment (EEE) is one of the fastest growing waste streams in the EU [1], and is expected to increase exponentially worldwide over the next few decades [2]. The EEE sector implements various Circular Economy (CE) practices to move from wasteful linear business models to cascading and resource efficient solutions along the EEE supply chain [3]. Value-retention processes (VRPs), enable the extension of the expected service life and activation of the full potential of recapturing resource value (materials, products, work load, energy, and functions) embedded in products beyond the recycling of materials [4–6].The value retention processes are a crucial part of cascading the materials flows in CE, and they are the entry point for further recycling of products, which are not feasible any more for VRPs. In the case of EEE, value retention services can be divided, as [7]:

- Full-Service Life Processes – which aim at providing a completely new life for every usage cycle of the product and they are performed in industrial settings (e.g., refurbishment and remanufacturing).
- Partial Service Life processes - which aim for the completion of, and/or slight extension of, the expected product service life (e.g., direct reuse and repair).

Remanufacturing is often seen as a resource-efficient and effective solution, which is key when aiming to reduce the negative impact of humans on the climate and environment [8]. One reason for this is that the embedded value that has been put into the making of materials, components and products are being salvaged through remanufacturing compared to material recycling, where products and their parts are being shredded [9]. This means, according to Bras and Hammond [10], that with remanufacturing, the economic and environmental values associated with the products are preserved.

The aim of this paper is to analyse the main challenges and drivers (internal and external) for remanufacturing (or refurbishment) in PaaS settings. Based on the review of the scientific literature, the scientific gaps are formalised with regard to the acceleration of the potential of remanufacturing in product-as-a-service (PaaS) with electrical and electronic equipment (EEE) for consumer markets (Business to Customer B2C).

The research questions are stated as follows:

- Q1: What are the different conditions of providing PaaS compared to selling products from the perspective of remanufacturing?
- Q2. What are the current challenges, drivers, and research gaps from a perspective of remanufacturing in PaaS?

1.1 PaaS Characteristics

PaaS is a special type of a product/service system (PSS) [11]. PSSs were heralded as one of the most promising measures for a resource efficient and circular economy [12], and indeed, could substantially increase resource efficiency, as reviewed in [13]. PaaS is still niche but is increasingly offered in B2C markets for EEE. Also, it is supported by the EU policy by being listed, as one of the foci in the EU CE action plan 2020 [14]. PaaS does not transfer product ownership to end users, and manufacturers keep the product under their control. Manufacturers are paid typically according to a contracted time period and are incentivised to use the product with its fuller technical lifetime, typically in multiple contracts. Remanufacturing, when compared to new manufacturing is characterised by higher variability (of, for example, core models) and uncertainty (of, for example, the timing of core arrival at a manufacturing facility) [15]. However, thanks to the feature of PaaS keeping control of the products in use, PaaS providers knowledge on which models will return, and on which day. In case the PaaS provider monitors and maintains the product in the use phase, they can better control and get pre-informed of the core quality, too. This is a significantly positive condition for the effectiveness and efficiency of remanufacturing. Therefore, remanufacturing in the PaaS context creates opportunities for new research.

1.2 Remanufacturing as a value retention process, and the prerequisites of remanufacturing in PaaS

Manufacturing companies are investigating their opportunities to retain the value of a used product through product value retention processes (VRPs) [16,17]. Remanufacturing is a VRP, which prepares used products and their components for a new use (reuse) through a controlled industrial process, and recaptures the inherent value of the product [18,19].Remanufacturing has a long history within the aerospace and automotive industry sectors; however, in recent years the EEE sector has been on the rise. Within the EU project European Remanufacturing Network (ERN), Sundin et al. [20] investigated several EEE remanufacturers, and 16 industrial business model cases from the EEE sector were described at ERN [21].

According to Vogt Duberg et al [16] there are four categories of essential prerequisites for remanufacturing: core acquisition and reverse logistics, labour skill and availability, remanufacturing facilities, and remanufacturing process and technology. Core acquisition and reverse logistics can be substantially supported by value network actors by having products sold as a service since the remanufacturing company then has the possibility to achieve better control of the products arriving at the remanufacturing facility [22]. Moreover, according to Sundin and Bras [22], the computer system controlling PaaS could be synchronized with the system used in remanufacturing to ease the administration at the remanufacturing facility. By using PaaS, the storage of products planned to be remanufactured is moved from the remanufacturing facility to the customer. These two opportunities gained by PaaS in connection with remanufacturing are ways to reduce the costs of remanufacturing [22]. Furthermore, having knowledge of when and how many products enter the remanufacturing process (through PaaS) will make it easier to plan and manage [22].

The combination of PaaS and product remanufacturing provides opportunities for the circularity of EEE products to become economically and environmentally beneficial to the value network actors.

2 RESEARCH METHODS

This study combines the gap analysis method with the summary of findings from the systematic literature review, which was conducted in the SCOPUS data base. First, scoping studies were performed, as recommended by Tranfield et al. [23], to identify boundaries and define search criteria. During the scoping studies, the recent systematic literature reviews on remanufacturing and circular economy practices in WEEE/EEE were studied [1,5,15,24,25]. Subsequently, the search criteria were defined, as in Table 1.

Table 1: Search criteria

Criteria	Description
Keywords	Product as a service (PaaS), product service systems (PSS), circular business models, remanufactur*, refurbish*, consumer goods, WEEE electrical and electronic equipment
Time range	2003-2022
Language	English
Type of documents	Journal, Conference proceedings
Authorship	defined

In order to ensure the transparency and clarity of this systematic literature review, the PRISMA 4 steps methodology was applied. In the first step 'Identification', from the Scopus database a data set of 124 articles were extracted that met the criteria of Table 1. In the second step 'Screening', duplicate or incomplete records were removed. Next (Step 3 – Eligibility check), the title and abstract were checked regarding the exclusion criteria, as follows: 1) a document presents a macro perspective & policy making, 2) a document does not include a description of the value retention process (remanufacturing or refurbishment); 3) a document focusses on policy making; 4) a document considers only recycling as an end-of-use scenario (EoU). After this step, the data set was reduced to 54 papers.

Finally (Step 4 – Inclusion), the full texts were screened for compliance with the following inclusion criteria: 1) at least one type of value retention process is described; 2) a paper considers electrical and electronic equipment (or WEEE); 3) a use case/example of PaaS (or other circular business model) is described. After reading the full text and their references a set of 35 were obtained from SCOPUS, the additional 8 papers from cross-referencing (snowballing), which met all the inclusion criteria, were added to the dataset for further investigation. Detailed bibliometric and content analysis was performed on a group of 43 articles. Data collected from the systematic literature review was used as input for the research gap analysis.

The steps of the classic gap analysis method have been modified as presented in Figure 1.

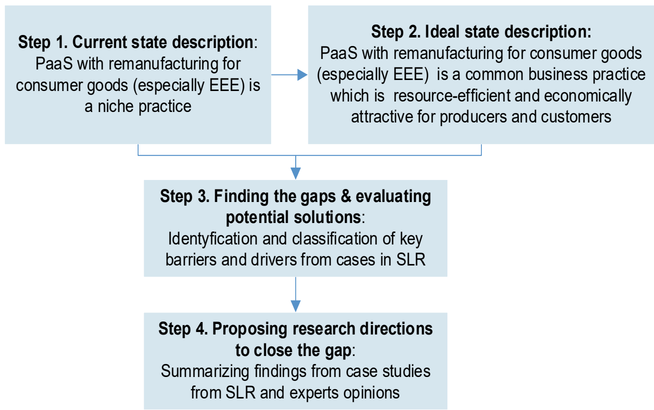

Figure 1: Gap analysis approach

3 CLASSIFICATION OF THE CHALLENGES AND DRIVERS FROM THE LITERATURE REVIEW

Due to the limitation of space in this paper, the detailed descriptive analysis of the bibliographic sample are not presented here. The focus of the paper is on content analysis. The results of the descriptive bibliographic analysis are available upon request.

The barriers and drivers for the development of remanufacturing in PaaS are classified here into six categories: 1) related to the product; 2) related to the regulations and policies; 3) related to the customer and market; 4) related to the servitized business model characteristics; 5) related to the characteristics of remanufacturing (or comprehensive refurbishment); 6) related to the take-back system (reverse logistics).

The categories are developed based on [7]. The summary of the content analysis of the dataset is provided in Table.2.

The focus was placed on the applicability of the findings to the management of remanufacturing process in PaaS settings.

Table 2: Summary of the findings from the systematic literature review

Category	Barriers	Source	Drivers	Source
Product (P)	PB1. Limited durability and quality of EEE for B2C	[17,26,27]	PD1. Feedback loop with customer to improve design and durability – user-centric design	[11,28,29]
	PB2. Limited design for disassembly & reassembly of EEE	[15,18,30–32]	PD2. Increased easiness to disassembly and modularity of EEE for B2C	[33–38]
	PB3. Shortening of use cycle-technological innovations	[38–40]	PD3. Smart digital technology to monitor use patterns and plan preventive maintenance	[1,41,42]
Policy and legislation (L)	LB1. Strong focus on recycling target for WEEE for B2C	[4,43,44]	LD1. Push in policy for extended durability and reparability	[45,46]
	LB2. Lack of taxation benefits for PaaS with reman/refurbish	[47–49]	LD2. Ecodesign regulations	[15,37]
	LB3. Lack of standards for reman/refurbish for EEE in B2C	[47,48,50,51]	LD3. Circular Economy Policies with PaaS and reuse	[1,5,46,52]
Customers & market (C)	CB1. Limited knowledge on the reman /refurbish EEE	[28,53–56]	CD1. Extended product warranty and hassle-free product usage	[28,54,57–61]
	CB2. Limited willingness to pay for reman/refurbish EEE	[53–56]	CD2. Access to functionality of EEE without initial purchase cost	[37,50,51]
	CB3. Limited acceptance, low demand for reman/refurbish EEE	[48,53–56]	CD3. Total cost of ownership distribution over time (e.g., subscription fee)	[17,62,63]
Servitized business model (S)	SB1. Additional cost of administration of PaaS, cash flow problems	[17,26,64,65]	SD1. Feedback loop with customers to iteratively improve PaaS offering	[17,27,39]
	SB2. Lack of actionable tools for jointly evaluation of economic benefits for OEMs and customers	[16,26,27,63,64,66]	SD2. Control over product use cycles (chance to optimize value in cascade CE model)	[37,50,67–69]
	SB3. Lack of actionable tools for jointly assessment of environmental benefits for OEMs and customers	[16,26,48,50,63,66]	SD3.Economic benefits from servitization (new revenues streams/access to new markets/shortening sale channels)	[28,37,39,54,70–74]
Process perspective (VRP)	VRB1. Limited/no experience in VRPs for EEE	[17,39,66]	VRD1. Reduced uncertainty of timing, quality, quantity of returns thanks to the OEM's ownership of EEE (lowering reman costs)	[18,22,66,69,73,75,76]
	VRB2. Limited access to skilled staff	[16,17,39,66]	VRD2. Economic benefits from use of EEE in multiple contracts	[12,16,26,37,48,50,61,66]
	VRB3. Linear mindset, fear of cannibalization of sale of new products	[17,39,48,49,75,77]	VRD3. Resource-efficiency by using value embodied in EEE	[16,26,32,37,48,50,60,66,76]
	VRB4. High costs- difficult to achieve the economy of scale in reman of EEE on B2C	[17,27,39,64,75]	VRD.4. Environmental benefits and green branding	[37,54,59,69,74]
Supply chain & reverse logistics (RL)	RLB1. High cost of establishing own take-back system (collection, transportation & testing)	[12,16,46,67,78,79]	RLD1. Subsidies to organize take back systems	[16,49, 50,58]
	RLB2. Need for new partnerships in configuration of RL	[16,49, 50,58]	RLD2. Resilience in a supply chain	[37,69]
	RLB3. Country-specific constrains on transborder transportation of used EEE/WEEE	[24,47,80]	RLD3. Cooperation between different actors	[80,82]

4 RESEARCH GAP

The final step of the research consisted of triangulating the results of the systematic literature review (Table 2) with the results of the five expert interviewers, who were involved in the industrial cases (each 60-90 minutes). Furthermore, the triangulation process included the authors' reflections on industrial cases they previously conducted (with remanufacturing in circular business models). The triangulation process confirmed the SLR findings. The additional challenges that were addressed by the experts were financial difficulties in providing feasible cash flow for scaling up the PaaS. There is a need for new financial partnership models, as at the beginning of PaaS contract, the production, logistics and administration costs are incurred by providers, but the future revenue stream is spread over a long period of time due to the nature of the servitization. More research is needed in this area of participation and collaboration in a supply chain. The tools and methods for calculating the joint economic and environmental benefits and costs for PaaS providers and customers are still very limited. The problems of organising the remanufacturing process (see [84]) and its sustainability assessment [85], which are observed in other more mature industries for remanufacturing, are crucial to overcome. Due to the pilot nature of most applications in industrial cases, evidence-based results are still missing. The future research direction shall consider to what extent PaaS will change the boundary condition that will decisively influence the operational factors as, for example, time for disassembly, material recovery rate, etc. The lack of remanufacturing experience and potentially high remanufacturing costs are often a concern for companies transitioning from linear to circular business models. Establishing efficient and lean remanufacturing processes is one of the main challenges facing linear producers today. Decision support frameworks and tools are lacking to support companies in their transition to PaaS business models with remanufacturing.

5 CONCLUSIONS

The paper presents a summary of the systematic literature review (SLR) on the challenges and drivers of remanufacturing in Product as a Service (PaaS) settings. The SLR findings were combined with the insights of industrial cases. Few analysed scientific papers provide evidence-based recommendations for scaling up EEE remanufacturing in the consumer market using PaaS. The existing research is fragmented, and the presented case studies are in the initial stage of development or implementation. Reducing barriers is critical to activate the drivers of change. Future work will focus on the empirical research with business cases to develop a decision-making framework for scaling up economically viable and environmentally beneficial remanufacturing for EEE in PaaS for consumer markets.

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