PRODUCT-AS-A-SERVICE FOR CRITICAL RAW MATERIALS: CHALLENGES, ENABLERS, AND NEEDED RESEARCH

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Abstract: The efficiency of using critical raw materials (CRMs) needs to be increased urgently in light of a circular economy (CE). This conference paper describes the benefits, current challenges, enablers, and needed research regarding product-as-a-service (PaaS) for CRMs in the context of a CE. In particular, it will analyse PaaS with electrical and electronic equipment (EEE) in the home appliance sector from five relevant perspectives: design, remanufacturing, recycling, costing, and regulations. Based on a literature review and analysis, important topics are documented, for instance, user-centred design, user behaviour, reverse logistics, cost assessment and allocation, use of Industry 4.0 technologies, and governmental regulations. Also, the importance of systemic innovation is pointed out.

1. INTRODUCTION

Critical raw materials (CRMs) are those raw materials that are economically and strategically important for the European economy, especially to its low carbon and digital transition, but which have a high risk associated with their supply [1]. Increasing material efficiency and circularity are seen by the EU as a crucial strategy to reduce the import dependency. Transitions to a CE can be notably accelerated by the adoption of product-as-a-service (PaaS) business models [2] that use a product with its fuller technical lifetime, typically in multiple contracts with OEMs' keeping the ownership of the products and having, to some extent, the responsibility for their performance throughout the lifecycles. Thus, PaaS is considered one of the most promising business models to enhance critical raw material (CRM) efficiency [3] and security. From the manufacturing companies' viewpoint, PaaS brings additional potential benefits such as business stability and supply chain resilience. However, not every PaaS offering in the current markets increases CRM efficiency, partly due to the absence of the full lifecycle approach and systemic activities. It is, therefore, essential that a new CRM-efficient PaaS business model be developed and implemented in industry as well as scientific insights to facilitate the practice being created and applied. To do so, various lifecycle activities must be innovated and adapted to the new CRM-efficient business models using the full lifecycle perspective.

This paper will report on an ongoing European project that aims to transform entire CRM value chains into more resource-efficient and circular systems for European interests. The major objective of this project is to demonstrate the performance of improved product design, remanufacturing, and recycling in the context of a CRM-efficient PaaS business model from the sustainability perspective. In addition, the project will aim for an even more improved systemic design of the CRM efficient PaaS business models and improve the knowledge under the systemic design for product design, remanufacturing, and recycling.

The specific objectives of this conference paper are to describe benefits, current challenges, possible solutions, and needed research regarding PaaS with electrical and electronic equipment (EEE) in the home appliance sector for CRMs. In particular, the paper will analyse PaaS from five perspectives of relevance, that is, design, remanufacturing, recycling, costing, and regulations. The research method adopted for this paper is a literature review and analysis.

2. BACKGROUND AND RELATED WORKS

2.1. Circularity of CRMs in EEE

Different definitions for CRMs were reviewed to conclude that many studies use a combination of two dimensions, namely, economic importance and supply risk [4]. In line with this majority, the EU has defined its own list of CRMs since 2011 and, in the 2020 list, identified 30 materials [5]: the EU acknowledges access to the CRMs is a strategic security question for Europe's ambition to deliver the Green Deal and can be facilitated by a CE [6]. An updated list of CRMs should be published by the EC together with the CRM Act in Spring 2023. Other countries also have similar lists: The USA identified 35 critical minerals that play an essential function in manufacturing products [7]. Australia, a major exporter of minerals, identified 24 critical minerals [8]. Below, some of the CRMs relevant to EEE in the EU 2020 list are discussed, especially concerning their circularity dimension.

Lithium is, in its majority on the global market, used for rechargeable batteries and thus is important for portable EEE. According to an estimation [9], ca 30% of the primary production of lithium is possible to be substituted for by recycled lithium, whereas less than 1% is currently recycled [6]: this gap shows a huge improvement opportunity, especially related to the economic viability of recycling. To increase the production of recycled lithium (and also of other CRMs such as cobalt), the EC aims, in particular, to significantly increase the collection rate of batteries, setting ambitious minimum material recovery levels for waste batteries and minimum recycled content for new batteries [10].

Indium is used in, for example, liquid crystal displays (LCDs) and is recycled less than 1% of the time [11]. Hardly available is a practical process to recover indium from LCDs in industry [11], although a newly proposed process was reported with over 90% of indium recovery efficiency by optimized grinding pre-treatment process [12].

Potentials and barriers of recycling tantalum were researched [13]: Tantalum is used in, for example, EEE components and is recycled less than 1% of the time. Although recycling tantalum from WEEE is generally possible, it is at present hindered because accurate separation of tantalum from PCBs (printed circuit boards) is impossible only by separating visually identifiable tantalum capacitors (VICs). Further, the research indicated that relevant equipment types have to be bundled to obtain a sufficient scale in terms of input masses.

Overall, recovery ratios of CRMs in waste from electrical and electronic equipment (WEEE) are largely low [14], and the extension of a lifetime through reuse is also highly limited in the EU [15].

2.2. PaaS with EEE for the CE

PaaS does not build upon material-centric approaches and thereby has the advantage of using the value embedded in the products [16]. The control and responsibility under PaaS are in stark contrast to the current practice for EEE, where OEMs have little control over the quality and quantity of material recycling. Specifically, a PaaS for washing machines on the B2C market was shown to have the potential to increase CRM efficiency by ca 40% [17]. In line with these insights, the EU, in its CE Action Plan 2020, sees innovative business models built in particular on PaaS as an accelerator of circularity and dematerialization [18].

Today, PaaS is observed in various markets globally, and thus far, they have been reported more from B2B (business to business) contexts. PaaS on B2C is increasingly available in Europe, with such examples as vacuum cleaners by Electrolux, heat pumps by Panasonic, and home appliances by BSH. However, PaaS is still a niche at present.

Performing PaaS businesses effectively and efficiently is complex because product design, remanufacturing, and recycling processes must be innovated and adapted using the lifecycle perspective; these processes also occur at different points, both temporally and geographically, but are interdependent [19]. Therefore, shifting to CRM-efficient PaaS business models on a large scale must be orchestrated within a value cocreation ecosystem [20]: it requires a longer-term commitment by involved actors [2], while making the shift successful is challenging [21].

2.3. Knowledge gaps

Barriers to a CE, in general, were categorized into technological, market, regulatory, and cultural; one issue is the lack of a larger-scaled demonstration of circular business models [22]. Little scientific insights are available for how PaaS offerings on the markets could be developed and deployed while contributing to the CRM efficiency, circularity, security of supply, and sustainability at large. In the consumer markets, even successful PaaS is rarely reported in the literature.

3. DESIGN

3.1. Value modelling

User profiles: because user requirements are constantly changing, providers of PaaS must constantly modify their product designs to satisfy them [23]. Earlier research has demonstrated that one major obstacle to the adoption of PaaS is that users' preferences for PaaS can be greatly impacted by a lack of ownership [24, 25]. To increase the acceptance of PaaS systems, user-centric design can help designers foresee how their products are used and if they are well accepted. However, this type of design becomes difficult to execute, especially for PaaS, due to the need for iterations with possible solutions and the general public, which could increase the development costs and is very time consuming.

Value scale: Future PaaS customers will need outcomes, performances, usage utility of the products, and a good experience in terms of economic, environmental, and social sustainability [23]. However, how users appreciate value remains subjective and may be influenced by culture, behavioural intentions, and socio-demographic characteristics, and it will change throughout the deployment of PaaS. The most coveted qualities by the various consumer segments will emerge during several rounds of value propositions and user experience, enabling the product design to employ both user feed-forward and feedback in terms of data, information, and expertise.

Use cases and patterns: Use cases are one of the most essential tools for user research and user experience design since they encompass a key step in the user-centered design (UCD) process, which could direct the approach of the majority of firms today when developing their applications and systems [26]. On the other hand, pattern-driven data is evolving into a crucial instrument for transforming the industrial economy into a knowledge economy and is also becoming an essential component of production factors and product design. Design should be accomplished from the individual skill-driven scenario to the group data-driven scenario. Nowadays, there is much information on use cases and patterns on web-based services; however, there is a lack of both on product-based services such as the leasing of products, making data-driven product design for leasing intentions almost impossible.

3.2. Lifecycle design and assessment

Assessment: Various enablers in design for the CE were proposed; see, for example, [27]. However, a major challenge is identifying and designing a lifecycle [28] [29] in such a way that different enablers are implemented for the intended system properties. Regarding the assessment of PaaS, several challenges were reported due to its complexity [30]), and a guideline for evaluating the environmental performance based on the life cycle assessment (LCA) methodology was proposed [31, 32], which was further expanded [33].

Value mapping to stakeholders: To develop a successful PaaS value proposition, numerous stakeholders should be included in the design process. However, often it is not clear who could be the potential stakeholders of PaaS, and identifying the potential value that the PaaS can offer to the stakeholders is challenging. Companies should explicitly and methodically consider stakeholders when creating a PaaS value proposition. This entails recognizing the knowledge and context of the system's main stakeholders and defining who they are: However, the stakeholders can also vary as the iterations between product service offerings and customer reviews start to occur [23].

3.3. Product design

Product functions: Functions are specified for what a product can fulfil, and they are usually described by nonquantitative statements. However, which functions are interesting for the service model? What parameters are the most important for future users? How can we adapt these functions to the value scale? And, can we integrate all the variants into one product-service? These are some of the questions that arise when developing a business case model for a user-centric product as a service design or function-oriented design.

Product design has been investigated to increase the recyclability and material efficiency of targeted materials. Disassemblability and modularity of products have often been used as key features [34]. Reuter et al. [35] on the CE context showed how the modular design of Fairphone 2 contributes to increasing the recyclability of, for example, magnesium, by analysing three recycling process technologies; further, materials such as gold, copper, silver, cobalt, nickel, palladium, platinum, gallium, indium, and zinc can all be recovered in high percentages (80 to 98%), and modularity promotes reparability and extension of the lifetime.

4. REMANUFACTURING

In the case of EEE for the consumer markets, pilot projects are run to explore PaaS scenarios in remanufacturing [36, 37]. The common problem in traditional remanufacturing is core (an end-of-use or end-of-life product) management. The problems with the availability of a sufficient quantity of good quality cores appear on open markets (e.g., for automotive components). Offering PaaS for customers (especially in B2C) might help to overcome this challenge as the ownership of the core remains with a producer, and the duration of the PaaS offering can be managed to capture the optimal value of a product and minimize the cost of remanufacturing (due to the good core quality). Furthermore, the integration of remanufacturing with product design can lead to the extended life of the product, and modular design could help to easily upgrade goods and to reduce the cost of repairs and recovery at a component level. The long-term data to assess those benefits is still missing to investigate the full picture (challenges and benefits in monetary units). The example of white goods manufacturers shows that there are a number of challenges, which shall be further explored and investigated in close cooperation with companies to provide actionable and feasible tools and solutions. The current challenges in PaaS with remanufacturing are further elaborated on in this section.

Customer behaviour: Existing studies show that the acceptance of remanufactured products differs between markets and customer segments [37]. Moreover, the education of the customers might be crucial to maximizing the chance for success and scaling up the PaaS offering for the future [38]. Studies have shown that consumers generally perceive remanufactured products to be of lower quality and, thus, anticipate paying lower prices for remanufactured products than new products when sold conventionally [39]. There is not enough data to assess whether a customer will be willing to pay the same fee on PaaS regardless of whether the product is new or remanufactured, as the risk and costs of repair are covered by PaaS. To establish an economically viable model, customers must return products at the end of the PaaS offering in good condition and on time [40]. This is crucial to reduce remanufacturing costs and achieve an economy of scale. IoT devices may be useful in collecting and processing data on customer behaviour to diagnose the current condition of a device so that an assessment can be made before the end of the PaaS contract. The research and practical applications are badly needed to support future decision-making on the most preferable recovery scenario in PaaS (e.g., full-scale remanufacturing, repair, cannibalisation for components, or recycling).

There is a challenge to jointly *optimize costs for producers and customers* (total cost of ownership TCO), as PaaS needs to be financially attractive and viable for both. Determining the total cost of a PaaS offering for producers can be tricky, and new tools are desperately needed to do the calculations. In ideal conditions, the PaaS model assumes several contracts with customers with remanufacturing/refurbishing in-between the contracts to return a product to its full functionality or upgrade it to the current market standards (e.g., energy efficiency) by changing modules or software. The costs of remanufacturing and repairs are borne by the producers, who therefore need to optimize their tools with the help of a lifecycle costing (LCC) approach. Setting the leasing fees correctly for a cascading model with few leasing contracts (with remanufacturing in between) requires a big set of data and analytic tools, which is currently challenging, as most of the PaaS in the B2C markets are small-scale pilots [41].

For customers, PaaS provides hassle-free use of equipment, as the maintenance and service costs are usually borne by the manufacturer. However, perceived benefits should not be overestimated, so different options may need to be offered for different customer segments, such as pay-per-use, multiple leases for new or remanufactured/refurbished products [42].

Administration of PaaS requires building new relationships with the current distributor on EEE markets in order to run the due diligence of potential customers (lower cost of executing the late or missing payments on B2C markets) and managing the flow of products to and from customers for purposes of remanufacturing before the next PaaS contract.

EEE is often subject to *technological innovations* (e.g., mobile phones, laptops, etc.). Current research [43] suggests that many critical materials are used mainly as alloying elements in EEE, which impedes their recovery and reuse at a product's end of life. The most problematic materials are dysprosium, samarium, vanadium, niobium, tellurium, and gallium, which often appear in low concentrations in alloys, making their recycling infeasible. In the case of EEE, better identification of the alloys' structure is needed, and the critical materials with low concentration and low recyclability shall be avoided. From the perspective of remanufacturing, the technological innovation concerning the energy or water efficiency of EEE may make remanufacturing a non-viable option, as older generations of remanufactured products may not be attractive to customers. For the transition of companies to the PaaS scenario, the development of new tools for assessment of the most economically and environmentally viable option for product recovery in PaaS.

Reverse logistics: The possibilities for closing the CRM loops by applying recycling technologies are influenced by the characteristics of end-of-life products (EOL) in which CRM is applied and sectoral practices in the development of take back-schemes [6]. In the current WEEE regulations, emphasis is placed on the collection and recycling of EEE. The recovery rate is defined on the aggregated levels. Thus most producers are not involved in the reverse logistics themselves and delegate it to specialized third parties.

From the remanufacturing perspective, the main challenge is the way the WEEE is currently collected, as products of different types from different producers are mixed and often damaged during the collection process. Such a situation is not acceptable from the point of view of remanufacturing, as the quality and availability of the core (economy of scale) significantly influence the cost and possibilities of remanufacturing. The scaling up of the PaaS will require building new partnerships in the EEE industry and re-designing the reverse logistics network. Further challenges will be optimizing the additional costs of shipping and core evaluation prior to remanufacturing.

Remanufacturing process organisation: Currently, EEE manufacturers are rarely involved in remanufacturing (excluding photocopiers). Lack of remanufacturing experience and potentially high remanufacturing costs are often a concern for companies transitioning from linear to circular business models. Remanufacturing is more labour intensive and has higher uncertainty of process parameters than conventional manufacturing [44]. Establishing efficient and lean remanufacturing processes is one of the main challenges for linear producers today [45]. In this research project, we aim to develop an actionable decision-making framework (strategic and operational) that could support the companies in their transition to PaaS business models with remanufacturing.

5. RECYCLING

Nonetheless, the involvement of the OEM in product recycling encompasses many possible advantages, including knowledge or more detailed estimates on the timing and volume of when different product models will return, the availability of information on how to best disassemble and recycle the returning products, and a higher potential for re-application of both the recovered components and recycled materials. Whereas many recycling companies in Europe were originally established by an OEM or are today subcontracted by extended producer responsibility (EPR) schemes that were set up by the OEMs, the direct involvement of OEMs in the recycling of WEEE or end-of-life vehicles (ELVs) is limited. Worldwide, only a few examples exist in which the WEEE recycling facility is owned and run directly by an OEM. One of these examples is Fujitsu in Fukushima, Japan, which operated a WEEE recycling facility located within Fujitsu's premises close to its R&D and production and with financial independence.

The increased adoption of PaaS business models by OEMs is believed to encompass the potential to drastically change this and result in a paradigm shift in how WEEE will be recycled. Since OEMs can retain ownership in a PaaS business model of the product they produce, they typically are also responsible for the reverse logistics. With reuse, repair, remanufacturing, and recycling in mind, returning products will be handled more carefully during reverse logistics. As products will typically return with distinct lifetimes, usage intensities, and conditions, an integrated or holistic approach is envisaged in which reuse, repair, and remanufacturing strategies will be prioritized in case the product functionality can be recovered when there is a sufficiently strong market demand for it, before proceeding to material recycling.

This holistic approach in a PaaS setting will, hence, require establishing a new decision-making framework and supporting tools at operational (operators), tactical (process managers), and strategic levels (interaction between the independent companies responsible for the recovery of WEEE and OEMs). For this, various Industry 4.0 technologies are considered crucial to increase economic viability and, hence, to accelerate the implementation of circular economy strategies and supporting processes [46]. Examples of these technologies include digital twins and product passports to improve the planning and control based on detailed and product-specific information.

Furthermore, the end-of-life treatment of WEEE and ELVs is today typically performed in an unstructured way, especially in the EU, resulting in sub-optimal retrieval of CRMs containing components and disappointing recovery rates for most CRMs [47]. In contrast, the systematic disassembly and separation of components containing high concentrations of CRMs, such as circuit boards, components herein, batteries, and electrical motors, have been demonstrated in prior research to be essential for both the reuse and the efficient recovery of the herein-containing CRMs. Therefore, a radically different approach is required to handle end-of-(first)-life EEE by means of product and component detection and (semi-) automated dismantling and handling. Whereas the adoption of such highly automated treatment strategies is today not feasible for the majority of WEEE, the adoption of PaaS business models in combination with Industry 4.0 computer vision, robotics, human-machine collaboration, and IoT technologies will drastically change the underlying conditions and increase both the technical feasibility and economic viability of systematic product disassembly for the integrated reuse, repair, remanufacturing and recycling. Since there is an inherent higher control of incoming product models and assured access to product information in PaaS business models, the potential also goes beyond systematic disassembly for improving the EoL treatment, such as the closed-loop or direct recycling of plastics and aluminium alloys. In prior research, substantial efforts have been devoted to investigating design for manual disassembly, repairability, and recycling, of which some results are under consideration for CEN/CENELEC standards relating to the Ecodesign Directive [48]. However, the systematic separation with high efficiencies of these CRM-containing components, in case performed manually under the European boundary conditions, is today characterised by low economic viability [49] [50]; this is expected to further worsen due to the continuous miniaturisation trend of EEE. Therefore, considering the increased adoption of Industry 4.0 technologies, there is a need to develop architectures and fastener designs to facilitate both non-destructive and destructive robotic dismantling, as well as novel robotic dismantling processes for products adopting these design changes. Finally, developing methods will also be essential to evaluate product designs in terms of the ease of dismantling and recycling by a human-robot collaborative system.

6. COSTING

Understanding the financial value of new business opportunities is critical to ensure the prosperity of enterprises. For manufacturers adopting PaaS business models, where the ownership of the sold products is retained by the provider and transactions are periodically reoccurring, there is no exception [51]. While such offerings can provide many financial benefits, manufacturers that have traditionally focused on selling products and transferring ownerships to users can no longer utilize their usual assessment methods since PaaS induces an extension of the system boundary – i.e., the factors impacting the financial outcomes of an offering – past the point of sales and warranty period. As such, earnings can no longer be maximized by solely developing products that last up to the point of high customer satisfaction to secure a recurring flow of transactions through a maintained willingness to pay [52]. Therefore, to retain product value over time and sell the products through multiple PaaS offerings, the products need to be taken back and remanufactured between the use phases [53].

Assessing the financial value of such setups has worked well in practice since manufacturers typically design products according to production costs, that is, the costs until the factory gate. However, when introducing PaaS offerings with an extended systems view past this gate, the traditional assessment methods suffer from incompatibility, hence the inability to provide the best practice and support in line with LCC [54] and product design practices that facilitate PaaS [55]. This results in many manufacturing companies entering an area not knowing how to properly exploit and assess the benefits of PaaS offerings, thus leading to a hesitance to introduce them on a full scale [56].

Even though researchers are highlighting a high and increasing number of published assessment methods for circular strategies (e.g., [57] [58]), there is a continued call for further research on LCC methods that are effective and easily applicable for practitioners [59] [60] [61]. One cause for this misalignment between the scientific contributions and best-known practice is that the LCC methodology has not been standardized, causing difficulties for practitioners to apply LCC in a lifecycle management context [62]. Additionally, since value-retention processes, such as remanufacturing [63], are frequently integrated into PaaS offerings, the LCC must also be capable of incorporating these activities adequately, thus further extending the level of difficulty [60]. To support manufacturers in introducing PaaS and to increase the body of knowledge in this area, research studies on practical experiences of applying LCC in PaaS transition contexts with integrated value-retention processes are needed. Such cases would map manufacturers' needs to effectively apply LCC given certain business models and industry circumstances.

Apart from financial benefits, PaaS can support closing the resource loop through the retained ownership of products. This drives manufacturers interested in securing their access to CRMs and used products (e.g., for higher resilience or value-retention processes), as identified in a market study on remanufacturing [64], and they have a greater incentive to care for the entire product lifecycle [32]. Ultimately, manufacturers are more incentivized to find solutions to overcome the challenges of transitioning from business-as-usual to offering PaaS and see perspectives beyond the costs.

In a PaaS model, the providers are, to a larger extent, impacted by use phase costs previously covered by the product owner [3]. Such costs are, for example, maintenance, transport, product deterioration, end-of-use recovery (e.g., remanufacturing), and administration of the offerings [61]. All these additions make it challenging from a cost perspective to transform a sales-based product offering and accurately determine fees that equal the same perceived value for customers and the financial requirements of providers [65]. Typically, to reach a lucrative position, extensive work is needed to design products for usage through multiple cycles [55] as well as to design PaaS offerings that provide benefits from both the provider and user perspectives. Simply exchanging the point-of-sales transaction with a periodic fee tends not to appear as lucrative and does not provide competitive cost-effectiveness [41].

With this view, LCC is highlighted as a valuable tool to develop an understanding of how PaaS can contribute to securing access to CRM and help companies transition to environmentally benign offerings, which, additionally, are financially sound. However, to utilize the full capabilities of LCC, further effort is required to advance methodological consistency.

7. REGULATIONS

The regulatory barriers to the PaaS model emerge largely as unintended consequences of regulations intended to serve other purposes. The broad reach of laws that protect consumers' rights and corporate profitability currently tends to promote linear sales models and product disposability [66]. For example, consumer protections that were enacted to prevent predatory lending may also prevent the effective deployment of PaaS systems, as in the case of the Netherlands, where a lease cannot run longer than 75% of the product's expected lifetime before converting into a sale [17].

PaaS systems are also hindered by the imbalance of access to information between consumers and retailers. In particular, retailers have developed a lucrative market for extended warranties that offer "profit margins of 44–77% and can represent as much as 50% of an independent retailer's profits" ([67] p. 224). The profitability of extended warranties indicates that consumers would be willing to pay for the peace of mind that PaaS systems offer but that retail strategies undermine the consumer's access to alternative more resource efficient consumption models. This situation highlights the conflict of interest between retailer and manufacturer and the challenge of balancing these interests with consumer protection. In particular, consumers do not know the likelihood of a breakdown or repair cost for any given product [67], and extended warranties take advantage of this information imbalance [68]. Extended warranties have thus far been immune to the enforcement actions that have impacted abusive rent-to-own and leasing contracts. The US FTC has brought enforcement actions regarding misleading rent-to-own [69] and vehicle leases [70], but the extended warranty market seems to fall into a gap in regulation.

PaaS systems offer an alternative model that would better align consumer and societal interests with manufacturer obligations, but this would come into direct conflict with the interests of retailers whose revenue depends on the division between consumers and manufacturers. Moreover, the retailer market provides an important consumer interest in ensuring competition between manufacturers and preventing tie-ins, which is still very much a problem in manufacturer warranty provisions [71]. Due to the many conflicting interests in the manufacturer-retailer-consumer-waste lifecycle of products retail supply chain, a new regulatory framework would be required to bridge the gap between the dominant linear sales model and a circular PaaS model.

In 2018, the EU Commission issued an amendment to the Waste Directive requiring member states to "promote and support sustainable production and consumption models" and "(b) encourage the design, manufacturing and use of products that are resource-efficient, durable (including in terms of life span and absence of planned obsolescence), reparable, re-usable and upgradable" (Directive EU 2018/851). Although this suggests that regulators are aware of the need for novel regulatory interventions, neither the EU nor any of the EU member states has thus far implemented a regulatory provision to further promote sustainable production and consumption models. The existing regulatory environment is too splintered to provide a clear path towards a circular economic model like PaaS. "Current tax schemes, regulations, supply chains and consumer habits are all geared into linearity, and thus new types of solutions face a multitude of institutional barriers" ([66] p. 672). This is not to say that a complete overhaul of product regulations would be necessary for PaaS systems to perform adequately in the market, but rather that small, deliberate regulatory adjustments could align PaaS models with existing market interests and regulations while protecting consumers from unnecessary warranty costs. Recent EU policy developments such as the Ecodesign for Sustainable Product Regulation proposal presented in the context of the Sustainable products initiative might offer specific opportunities in this area as it suggest to "increasingly invest in and incentivise the uptake of circular business models […], including product-as-a-service models, […] in addition to making sustainable products the norm" [72].

8. CONCLUDING DISCUSSION

Contributions of this conference paper lie in the description of i) different conditions of providing PaaS on the consumer markets of EEE compared with selling products, ii) PaaS' benefits for CRMs, and iii) the current challenges, enablers, and needed research. These were documented from the five inter-related perspectives of relevance (see Sections 3 to 7) so that the importance of systemic changes for exploiting the full potential of PaaS was highlighted. PaaS is a type of product/service system that has long been researched [23, 73], offering some useful insights into PaaS. Despite increasing interest in PaaS from policymakers and businesses in the EU, also indicated by recent consultancy reports [74, 75], little scientific research, research-based evidence, and evidence-based recommendation is available for more far-reaching effects on how PaaS could be developed and deployed on the markets effectively and efficiently, in particular, for the consumer markets of EEE. Providing PaaS differs immensely from selling products and hence requires different approaches and knowledge, although the common importance of designing physical products remains. Thus, this paper contributed to filling the void in the scientific literature. The main future work is to conduct empirical research with business cases on the markets, which the authors have begun.

9. DISCLAIMER

The views expressed in the article are personal and do not necessarily reflect the official position of the European Commission.

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