D.5.5. Report on practitioners' capacity building (for journal paper)

for the SCANDERE (Scaling up a circular economy business model by a new design, leaner remanufacturing, and automated material recycling technologies)

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Aim

The purpose of this document is to present deliverables 5.5. in the Scandere project, which presents a novel capacity building model Rem-Cap-Up that helps companies scale up remanufacturing in PaaS settings for EEE in consumer markets (B2C). The model combines the individual and organisational levels. Remanufacturing restores used products to like-new condition, supporting product value retention in circular business models. Product as a Service (PaaS) is an example of a servitised business model that allows companies to create value by proactively managing the lifecycle of their products. Currently, remanufacturing in PaaS is a niche practice for electrical and electronic equipment in consumer markets. The individual level allows for identification of critical skills of employees needed for remanufacturing. The organisational level combines the requirements for establishing a PaaS business model, the design of process, and the provision of the necessary resources for an economically viable and environmentally beneficial remanufacturing process, referred to as "lean and green". The framework takes into account the conservation of critical raw materials.

The following research methods are applied: literature review, longitudinal case study with semi-structured interviews, gap analysis, process mapping, and observation to establish the remanufacturing process and identify the necessary capabilities.

The report presents the following answer to the research questions.

1) What key challenges of remanufacturing of EEE in PaaS must be addressed when building capacities in a company?

2) What capacities are needed to overcome the challenges?

3) How to develop the necessary capacities in a company? The results focus on providing practical guidelines for companies on how to establish and scale up remanufacturing in PaaS settings.

Model for practitioners' capacity building for remanufacturing in product-as-a-service (PaaS)[1]

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Abstract

Remanufacturing restores used products to like-new condition, supporting product value retention in circular business models. Product as a Service (PaaS) is an example of a servitised business model that allows companies to create value by proactively managing the lifecycle of their products. Currently, remanufacturing in PaaS is a niche practice for electrical and electronic equipment in consumer markets. The aim of this paper is to present a novel capacity building model Rem-Cap-Up that helps companies scale up remanufacturing in PaaS settings for EEE in consumer markets (B2C). The model combines the individual and organisational levels. The individual level allows identification of the critical skills of employees needed for remanufacturing. The organisational level combines the requirements for establishing a PaaS business model, the design of process, and the provision of the necessary resources for an economically viable and environmentally beneficial remanufacturing process, referred to as "lean and green". The framework takes into account the conservation of critical raw materials. We apply the following research methods: literature review, longitudinal case study with semi-structured interviews, gap analysis, process mapping, and observation to establish the remanufacturing process and identify the necessary capabilities. We search the answers to the research questions1) What key challenges of remanufacturing of EEE in PaaS must be addressed when building capacities in a company? 2) What capacities are needed to overcome the challenges? 3) How to develop the necessary capacities in a company? The results focus on providing practical guidelines for companies on how to establish and scale up remanufacturing in PaaS settings.

Keywords: Circular economy; remanufacturing; value-retaining process; capacity building, servitisation, critical raw materials

[1] This paper was accepted and presented at the 7th International Conference on Remanufacturing (ICoR), 8-10 April 2025, in Amsterdam in conjunction with ReMaTec 2025, https://remanufacturing-conference.com/
This revised version includes the feedback from the ICoR reviewers and the discussion during ICoR

Introduction

Remanufacturing plays a pivotal role in facilitating the circular economy, as it enables the restoration of used products to a condition comparable to new, thus extending product life cycles and minimising resource depletion (Goltsos et al., 2019). Academic research on remanufacturing has predominantly focused on open-loop systems, where key challenges stem from inefficiencies in core acquisition and collection, as well as the limited effectiveness of existing control mechanisms (Paul et al., 2024). Research further indicates that remanufacturing is inherently more complex than conventional manufacturing. That results from the uncertainty associated with the quality, quantity and timing of returned cores (used products) and their recovery (Golinska-Dawson, 2019).

The emergence of Product-as-a-Service (PaaS) represents a paradigm shift in remanufacturing research, redefining its operational boundaries by establishing a closed-loop supply system that significantly mitigates uncertainties related to core availability (Golinska-Dawson et al., 2024). PaaS is classified as a subcategory of Product-Service Systems (PSS) (Brissaud et al., 2022) and is increasingly recognised as a promising model for improving resource efficiency while optimising the use of critical raw materials (CRM) (Sakao et al., 2023).

In PaaS circular business model, the ownership of cores remains with the original equipment manufacturer (OEM) or PaaS provider. That allows for proactive management of contract duration to maximise product value and potentially minimise remanufacturing costs (Golinska-Dawson et al., 2024). This reduction in costs is mainly attributed to the improved core quality thanks to controlled product usage and maintenance. Furthermore, the integration of digital technologies and life cycle data analytics enables OEMs to gain real-time insights into the health and condition of products (referred to as core quality) (Sakao & Nordholm, 2021). PaaS facilitates more effective planning and management of remanufacturing operations, leading to a reduction in overall costs (van Loon & Van Wassenhove, 2020). Compared to traditional open-loop remanufacturing, which is often constrained by variability in core availability and quality, PaaS offers more favourable conditions to optimise remanufacturing efficiency. Consequently, this approach enhances both the effectiveness and the resource efficiency of remanufacturing processes, supporting a more sustainable and circular production system.

The Circular Economy Action Plan (CEAP) of the European Union (EU) (COM/2020/98 final) identified the electronics and electrical equipment (EEE) sector as one of the sectors with the highest potential for circularity. At the same time, the dominant industry practice for waste electronics and electrical equipment (WEEE) is recycling. A change is needed to reduce reliance on recycling, which is not the most optimal solution for resource efficiency and sustainability (Howard et al., 2022). In order to unlock the circularity potential of the EEE sector, several actions are required, such as improving the durability, reusability, upgradability, and reparability of the product (Bressanelli et al., 2020; Cole et al., 2019). Furthermore, the implementation of value retention processes (VRPs) in particular remanufacturing is needed (Russell & Nasr, 2023).

Most of OEMs, especially in the EEE sector, currently lack the capacities to incorporate remanufacturing into existing manufacturing systems. Research shows that a number of challenges must be overcome to initiate remanufacturing (Duberg et al., 2023; Kurilova-Palisaitiene et al., 2020, 2024; Vogt Duberg et al., 2023). To scale up remanufacturing in EEE in PaaS settings, companies need to develop the necessary capacities at the organisational and individual level (workers and managers). Capacity building is defined here as the process of developing and strengthening the skills, resources, processes and competencies of individuals and organisations so that they can effectively achieve their goals, solve problems, and improve their performance over time (UN, 2024). Consequently, capacity building for remanufacturing are activities which help companies and their employees to become more efficient and circular in remanufacturing.

The aim of this paper is to present a novel capacity building model Rem-Cap-Up that helps companies scale up remanufacturing in PaaS settings for EEE in consumer markets (B2C). The model combines the individual, organisational levels and setting the enabling environment. The individual level allows identification of the critical skills of employees needed for remanufacturing. The organisational level combines the requirements for establishing a PaaS business model, the design of process, and the provision of the necessary resources for an economically viable and environmentally beneficial remanufacturing process, referred to as "lean and green". The enabling environment results from activating the stakeholder in building an efficient take-back system, engaging customers, and advocating for necessary chain in legislation. The results focus on providing practical guidelines for companies on how to scale up remanufacturing in PaaS settings. In this paper, we merge the remanufacturing and PaaS perspective and search for answers for the research questions:

- RQ1: What key challenges of remanufacturing of EEE in PaaS must be addressed when building capacities in a company?
- RQ2: What capacities are needed to overcome the challenges?
- RQ3: How to develop the necessary capacities in a company?

The results focus on providing practical guidelines for companies on how to establish and scale up remanufacturing in PaaS settings. The structure of the paper is as follows: first, the theoretical background is summarised in Section 2; second, the research methodology is presented in Section 3. The novel model and its application are discussed in Section 4. Finally, the conclusions are summarised in Section 5, followed by the future research directions.

Literature review – from challenges to capacities

The challenges for remanufacturing in open-loop systems can be linked to internal and external factors (Golinska-Dawson, 2019). The external challenges predominantly related to:

- Product suitability for remanufacturing (Design for R, product modularity & upgradeability, proneness to technical obsolescence) (Hatcher et al., 2013)
- Core acquisition and core management resulting from uncertainty in availability of cores (quality, quantity, timing) (Kurilova-Palisaitiene et al., 2018; Butzer et al., 2016);
- Limited balance of supply and demand (Kawa & Golinska, 2010; Kurilova-Palisaitiene et al., 2018);
- Poor core information from manufacturing and usage phase (Rizova et al., 2020);
- Uncertain/insufficient demand (Golinska, 2013) and customer willingness to pay (Vogt Duberg et al., 2020);
- Insufficient logistics network (Golinska-Dawson, 2019);
- Legal regulations (Dalhammar et al., 2021).

The internal challenges related to remanufacturing process organisation and management:

- Variable lead times/uncertain lead time and multivariant operations depending on the core quality (Kurilova-Palisaitiene et al., 2018); (Gaspari et al., 2017); (Butzer et al., 2016);
- Availability of spare parts and related information (Richter et al., 2023)
- Quality standards (Cui et al., 2017)
- Materials matching restrictions (Shi & Min, 2015)

- Lack of integration between flows of information and materials (Kurilova-Palisaitiene & Sundin, 2015);
- Inventory management and control (Zhang et al., 2019);
- Variability of cores in the process and stochastic routings depending on core quality (Rizova et al., 2020; Zlamparet et al., 2017)

In PaaS models, the conditions for performing remanufacturing are changing. Due to the extended control over cores by OEM (or designated PaaS providers) the cascade model can be proactively managed by facilitating decisions on remanufacturing, repair, and recycling especially for CRM (Jensen et al., 2019; Kjaer et al., 2018, 2019). The economic advantages of remanufacturing within PaaS frameworks stem from the generation of additional revenue streams through multiple contracts and the utilisation of cost-effective remanufactured spare parts for servicing (Pialot et al., 2017). PaaS contracts streamline sales channels and establish a direct communication link with end users, mitigating reliance on retailer networks. Furthermore, the integration of Internet of Things (IoT) into PaaS products enables real-time monitoring of usage patterns and product conditions, facilitating more effective planning and organisation of remanufacturing processes (Vogt Duberg et al., 2021). Direct customer engagement facilitated by PaaS further enhances iterative refinement of remanufacturing strategies (Arredondo-Soto et al., 2022).

A significant challenge for OEMs in implementing value retention processes (VRP) for electrical and electronic equipment (EEE) lies in their limited experience with remanufacturing. Compared to traditional manufacturing, remanufacturing is more labour-intensive and requires a workforce with advanced technical knowledge due to the variability of job routines (Golińska-Dawson, 2019). Consequently, acquiring skilled workers presents a considerable obstacle (Kurilova-Palisaitiene, 2021). Additionally, a linear managerial mindset focused on maximizing sales of new products often hampers the establishment of successful remanufacturing operations (Widera & Seliger, 2015). Even when adopting PaaS, companies remain apprehensive about potential sales cannibalization by remanufactured products (Yang et al., 2018). To enhance circularity in PaaS models, proactive product life cycle management is essential, ensuring the collection of products with high value at the end of use (EoU) rather than at the end of life (EoL). The schema of remanufacturing in PaaS is presented in Figure 1.

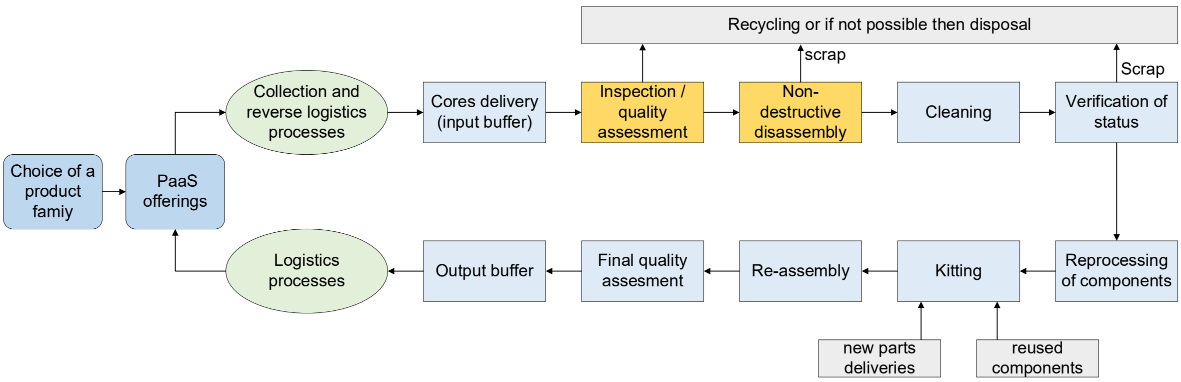

Figure 1 - Remanufacturing in PaaS (adopted from Golinska-Dawson et al. 2024)

Integrating remanufacturing within PaaS creates potential for increased resource efficiency by minimising the consumption of natural resources, raw materials, energy, and waste, thus preserving the embedded value of EEE from its initial production phase (Morseletto, 2020). Economic benefits in PaaS arise from the reuse of EEE components in multiple cycles (Gülserliler et al., 2022; Krystofik et al., 2018; Krystofik & Gaustad, 2018). In the EEE sector, extending product life contributes to sustainability by reducing the frequency of replacements

(Boorsma et al., 2021). Furthermore, OEMs' commitment to environmental sustainability and green branding can incentivise the expansion of remanufacturing initiatives (Vogtlander et al., 2017).

A major hurdle in implementing PaaS remanufacturing is the lack of an efficient take-back system among OEMs. Almost half of discarded electrical and electronic equipment (WEEE) in Europe is either improperly collected or unreported by EU member states (Habib et al., 2022). Customer involvement in proper disposal is limited, and many opt to either discard WEEE as household waste or retain unused products at home (hoarding). Some WEEE streams are combined with mixed metal waste and recycled without adhering to WEEE regulations. Scaling up remanufacturing within PaaS requires the establishment of new partnerships in the EEE sector and the redesign of reverse logistics networks to enable efficient sorting and assessment of returned products before remanufacturing (Parajuly & Wenzel, 2017; Prajapati et al., 2022). The current WEEE collection process complicates remanufacturing due to the mixing of different product types from various manufacturers, making sorting both costly and time-intensive (Anandh et al., 2021). Additional constraints include cross-border transport restrictions on used EEE, which hinder the development of centralised remanufacturing facilities and instead necessitate the formation of less profitable decentralised operations (Svensson-Hoglund et al., 2021).

For PaaS models to be economically viable, it is crucial that customers return products in good condition and within the designated contract period. This approach significantly reduces remanufacturing costs and facilitates economies of scale. Financial incentives, such as subsidies, could alleviate cash flow challenges while supporting the organisation of dedicated take-back systems and fostering collaborations across the value chain (Brito et al., 2022; Hansen & Revellio, 2020). Additionally, strengthening supply chain resilience is essential to ensure the availability of spare parts and materials for cost-effective and timely remanufacturing in PaaS models (Vogt Duberg et al., 2020).

Existing studies on remanufacturing in PaaS for EEE are still limited. The findings are predominantly based on the pilot project commenced by OEMs (van Loon et al., 2022). To scale up remanufacturing in PaaS and overcome the related barriers, there is a need to develop the necessary capacities. In the literature, there are limited examples of capacity models for remanufacturing, especially in the context of PaaS. Capacity building for remanufacturing involves developing the infrastructure, technical expertise, and alignment with the business model to efficiently recover end-of-use or end-of-life (EOL) products into remanufactured goods. There are relatively few examples of capacity models for remanufacturing in the context of circular business models. The areas of the capacity building models can be classified as:

- Developing infrastructure and technical resources, including facilities for the disassembly, reprocessing, and reassembly of products (Kurilova-Palisaitiene et al., 2024);
- Developing skills, including training programs and initiatives to enhance the skills of the workforce in remanufacturing processes (Chigbu et al., 2024), especially in using the advance modern technologies (e.g. additive manufacturing) (Alghamdi et al., 2017; Bressanelli et al., 2017; Panagou et al., 2023); and applying smart technologies to recover, process, and analyse product life cycle information (Mejía-Moncayo et al., 2023; Nwankpa et al., 2023)
- Aligning business model and strategic focus on circularity, including implementing decision support systems to optimise remanufacturing processes based on product complexity and demand (Kurilova-Palisaitiene et al., 2023; Vogt Duberg et al., 2023).
- Improving the suitability of the product for remanufacturing through Design for R and increased durability and reparability (Boorsma et al., 2021; Hilton, 2024).

- Mastering the reverse logistics (Kurilova-Palisaitiene et al., 2024; Vogt Duberg et al., 2023)
- Understanding market demand for remanufactured products and educating consumers about their benefits and willingness to pay (Koller et al., 2020; Kurilova-Palisaitiene et al., 2024; Vogt Duberg et al., 2023)
- Understanding quality standards to ensure the reliability and acceptance of remanufactured products and legislation for circularity (Wasserbaur et al., 2022).

The existing models focus predominantly on the initialisation of remanufacturing (Duberg et al., 2023; Vogt Duberg et al., 2020, 2023) improving the remanufacturing process (Butzer et al., 2017; Kurilova-Palisaitiene et al., 2024), or establishing PaaS with R strategies (Hidalgo-Crespo, Riel, Duberg et al., 2024; Hidalgo-Crespo, Riel, Golinska-Dawson et al., 2024). The novelty of this paper comes from the alignment of remanufacturing capacity building and a circular business model PaaS.

Methods

To develop the proposed Rem-Cap-Up model, we adopted a multi-method approach that integrates findings from a systematic literature review (SLR) with expert consultations, and three case study data. The combination of qualitative and quantitative research methods ensures a robust and comprehensive understanding of the research problem (Tranfield et al., 2003). A visual representation of our methodological approach is presented in Figure 2.

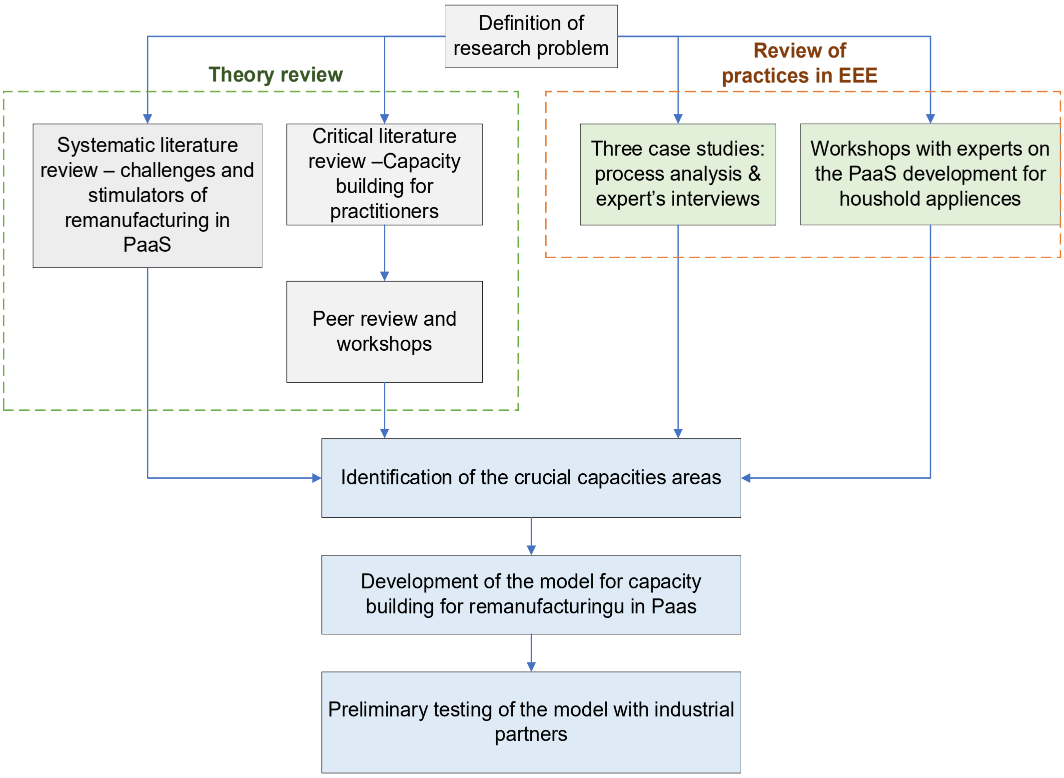

Figure2 - Research Methodology for REM-Cap-Up

The systematic literature review was conducted following the PRISMA guidelines (Moher et al., 2010) to ensure transparency, rigor, and replicability. The review included challenges and enablers of remanufacturing in PaaS for EEE. The results of this review, are presented in Golinska-Dawson et al. (2024). Then, a critical review was performed for industrial report and scientific literature on capacity building in the context of circular economy to identify applicable approaches. To ensure the reliability and applicability of our findings, we employ methodological triangulation (Bryman, 2016), combining insights from literature reviews with expert opinions, and industry reports. Key findings from the systematic literature review were validated through a series of online workshops on PaaS development involving academic and industry stakeholders from five different countries in the European Union. The discussions focused on refining the applicability of the proposed framework, identifying potential barriers to implementation, and aligning academic insight with industry needs. The results of the PaaS model development are presented in work by Hidalgo-Crespo et al. (2024). By integrating systematic literature analysis, expert validation, and industry perspectives, this study ensures methodological rigour while maintaining practical relevance for decision-makers.

The model development

The Rem-Cap-Up model is developed following the steps:

1. Identification of the challenges for scaling up remanufacturingu in PaaS;
2. Defining the key areas of capacity building model &configuration of the model;
3. Testing based on the data from case studies.

Identifying the key challenges for scaling up remanufacturingu in PaaS

In context of PaaS, we filter the challenges and enablers to remanufacturing of EEE from systematic literature review, by assessment of 5 independent experts. The results with the detailed analysis can be found in Golinska-Dawson et al. (2024), the summary is delignated in Figure 3.

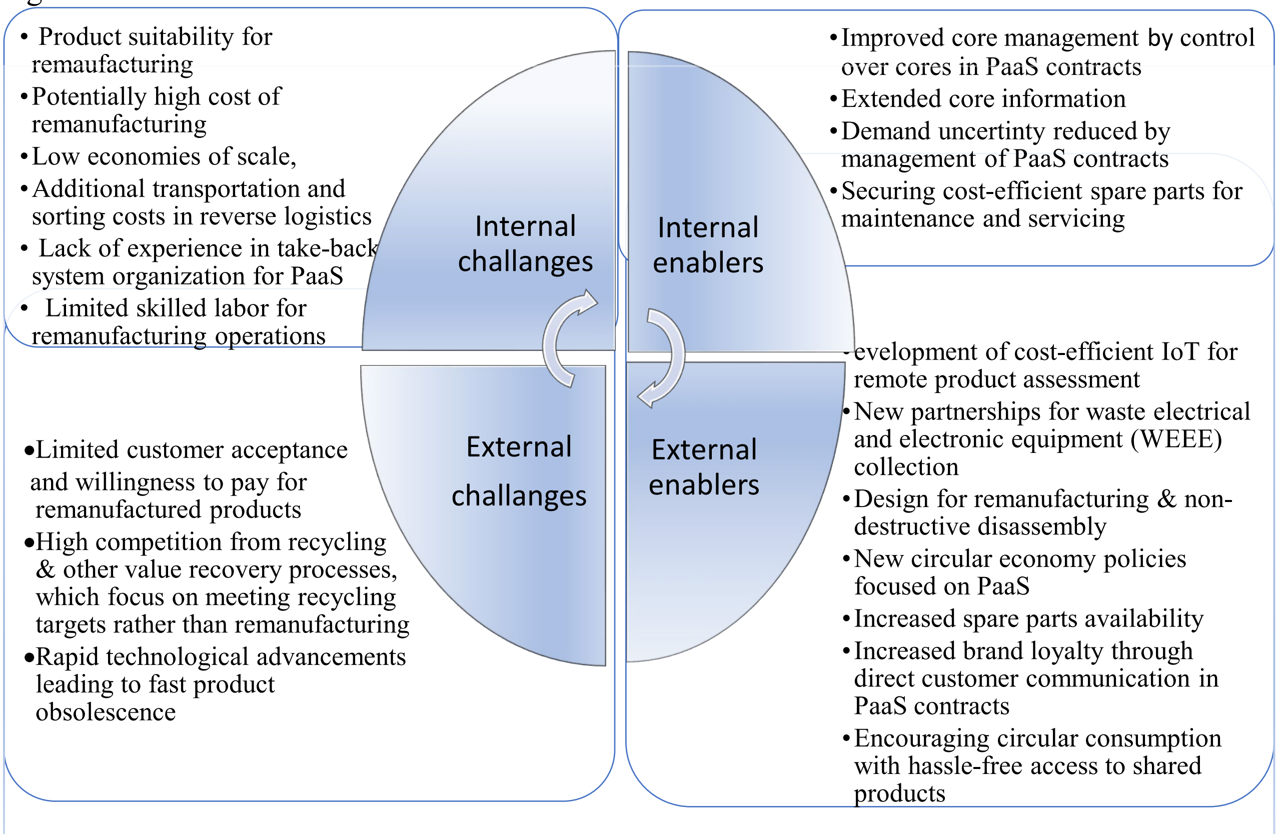

Figure 3 - Main challenge and enablers of remanufacturing in PaaS (based on Golinska-Dawson et al. 2024)

Recommendations from the literature review and expert's assessment:

- *Strengthening OEM Control Over Core Management*

To optimize core management and improve the efficiency of the remanufacturing process, advanced tracking technologies, such as radio-frequency identification (RFID) and Internet of Things (IoT) sensors, should be integrated. These technologies enable real-time monitoring of product usage and facilitate efficient core retrieval. Furthermore, OEMs should establish customer incentive programs to encourage the return of used products, thereby improving take-back rates and ensuring a steady supply of cores for remanufacturing.

- *Enhancing Product Design for Circularity*

To mitigate challenges related to product design in remanufacturing, OEMs should adopt modular design principles that facilitate ease of disassembly, modularity, component replacement, and material recovery. Design-for-remanufacturing (DfRem) methodologies should be embedded in product development processes, ensuring that components can be reused, replaced or upgraded efficiently. Additionally, the incorporation of standardized interfaces and interchangeable parts can further improve the feasibility of remanufacturing operations.

- *Optimizing the Cost-Effectiveness of Remanufacturing*

Remanufacturing is labour-intensive; thus, OEMs should focus on automation and process optimization techniques to improve cost efficiency. The establishment of regional remanufacturing hubs can help minimise transportation costs and reduce the overall environmental impact of logistics. Furthermore, digital technologies such as artificial intelligence (AI) and machine learning (ML) should be leveraged to optimise decision-making in assessing the economic viability of remanufacturing.

- *Improving Reverse Logistics and Collection Systems*

Efficient reverse logistics (RL) is critical for ensuring a consistent supply of high-quality cores. To address current inefficiencies, OEMs can develop blockchain-enabled tracking systems for real-time monitoring of core returns. Partnering with specialized reverse logistics providers and implementing automated sorting and quality assessment mechanisms can significantly reduce the costs and complexity of handling of returned products.

- *Addressing Workforce Skill Gaps in Remanufacturing*

The successful adoption of remanufacturing in PaaS requires a skilled workforce with expertise in disassembly, reassembly, and quality assurance processes. To address existing skill gaps, OEMs should invest in training programs, industry-academic collaborations, and professional certification initiatives. Establishing partnerships with universities and research institutions can further support knowledge transfer and innovation in remanufacturing techniques.

- *Leveraging IoT and AI for Smart Product Assessment*

Integrating IoT-based predictive maintenance systems can enable remote monitoring of product condition, allowing OEMs to proactively determine the optimal timing for remanufacturing interventions. AI-driven analytics can further assist in assessing the feasibility of remanufacturing versus alternative value retention processes (VRPs), thereby enhancing decision-making efficiency.

- *Strengthening Customer Engagement and Acceptance of Remanufactured Products*

An important barrier for adopting remanufactured products in PaaS is limited consumer acceptance. To overcome this challenge, OEMs should implement customer education initiatives that emphasize the economic and environmental benefits of remanufactured products. Providing extended warranties, performance guarantees, and transparent communication regarding product reliability can help build consumer trust and acceptance.

- *Mitigating Competitive Pressures from Recycling and Alternative VRPs*

The transition from traditional recycling-focused strategies to remanufacturing-driven circular economy models requires differentiation from other value recovery processes. OEMs should emphasise the lifecycle cost savings and good quality of remanufactured products. Additionally, the development of premium remanufactured product lines with enhanced functionalities (such as software upgrades and extended support services) can create the additional value proposition for consumers.

- *Addressing the Risk of Technological Obsolescence*

Rapid technological advancements pose a risk to the viability of remanufacturing in PaaS. To mitigate obsolescence risks, OEMs should adopt upgradeable hardware architectures that enable component-level upgrades rather than full product replacements. Software-driven innovations, such as updates and cloud-based service enhancements, can further extend product lifespan and maintain competitiveness in dynamic technological landscapes.

Key areas for capacity building

To address the challenges associated with remanufacturing, original equipment manufacturers (OEMs) must prioritise actions that enhance product quality and durability, evaluate customer willingness to pay, and establish cost-efficient remanufacturing processes and reverse logistics systems. A crucial first step involves implementing actionable approaches to assess product durability and quality, ensuring their suitability for remanufacturing within the PaaS. This should be complemented by an increased focus on design for disassembly and product modularity, which facilitate efficient end-of-life product management. Furthermore, OEMs require analytical tools to better understand customer acceptance and pricing expectations for remanufactured products in PaaS. Currently, the potential market size and acceptable price points remain largely uncertain, creating a barrier to scaling up remanufacturing efforts. Addressing this knowledge gap is essential for informed decision-making and strategic planning. From the perspective of a servitised business model, OEMs must develop strategies that balance their own economic sustainability with the financial benefits delivered to customers.

In PaaS, customers pay for performance rather than product ownership; therefore, economic advantages should be structured in a way that renders the distinction between remanufactured and new products irrelevant. This shift has the potential to significantly expand the market share of remanufactured electrical and electronic equipment (EEE). One of the primary obstacles to remanufacturing within PaaS is the cost-effective organisation of the process. Currently, standardised cost models for remanufacturing in PaaS are lacking, and OEMs often have limited prior knowledge regarding the relevant cost categories and their associated values. To address this, the development and implementation of novel tools are required to estimate product residual value. That can enable informed decisions on whether remanufacturing is economically viable for subsequent PaaS cycles or whether products should be redirected to recycling.

Additionally, OEMs require support in determining the necessary production volumes to achieve economies of scale in remanufacturing. To enhance decision-making, practical tools should be introduced for collecting and analysing data on reverse logistics costs. OEMs must be equipped with mechanisms to evaluate whether to establish own take-back systems or participate in collaborative initiatives. Furthermore, exploring incentive structures to foster partnerships in take-back systems can enhance the efficiency and feasibility of remanufacturing operations.

To address the identified challenges for remanufacturing in PaaS we propose a novel Rem-Cap-Up model, which is structured as presented in Fig.4

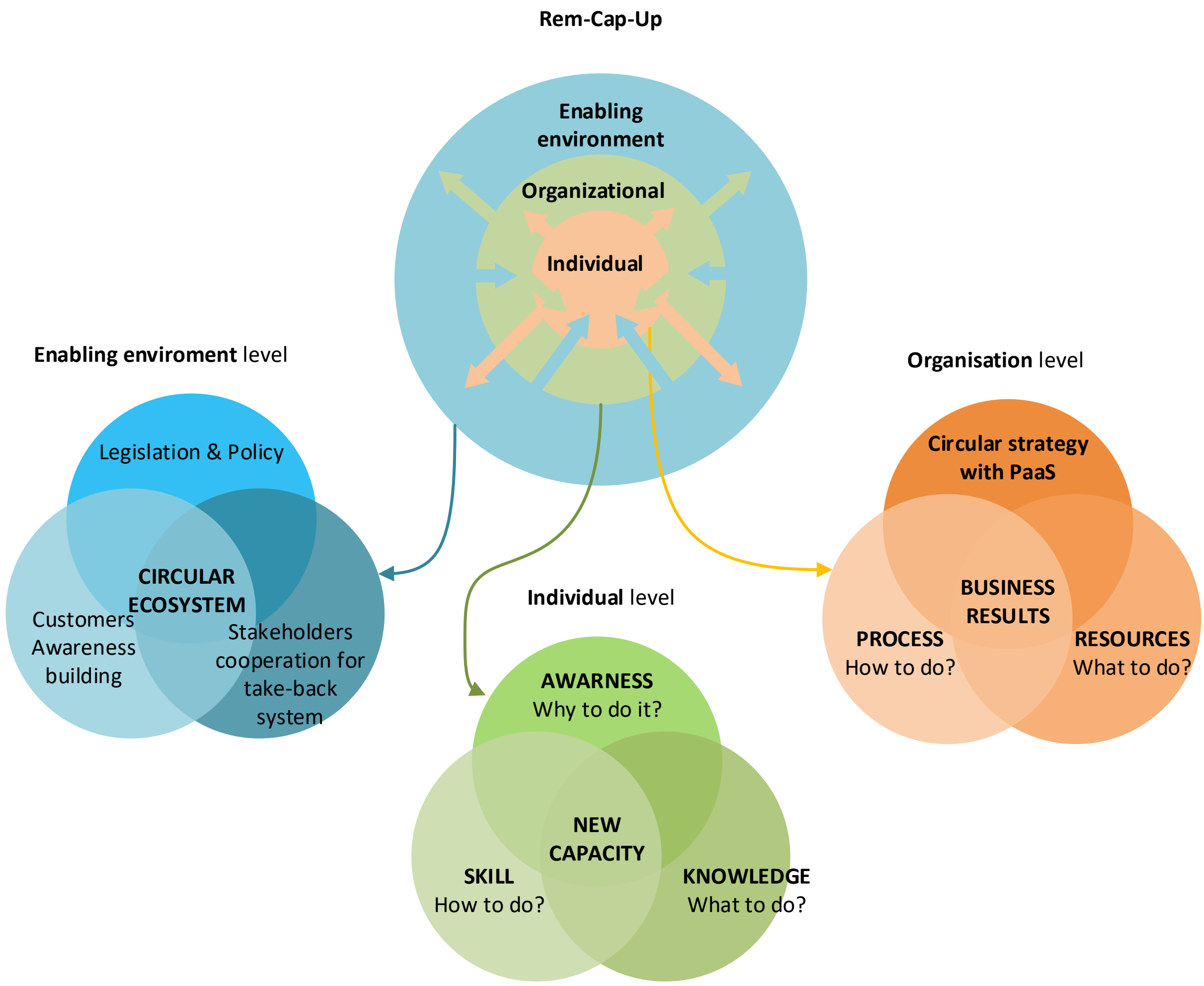

Figure 4 - Rem-Cup-Up model (inspired by FAO, 2024)

The model includes:

- *Individual Level*: The focus is on developing the essential competencies of employees and managers across three organisational tiers: operational (employees engaged in remanufacturing and related processes), tactical (middle management), and strategic (business owners, senior management, etc.). The model follows a structured, progressive framework that begins with awareness creation, advances through knowledge development, and culminates in the continuous enhancement of skills.
- *Organisational Level*: The emphasis is on developing the necessary resources, optimising cost-efficient remanufacturing processes, and aligning them within the Product-as-a-Service (PaaS) business model and circular strategy.
- *Enabling Environment Level:* The focus is on fostering collaboration with business partners to establish an efficient take-back system, enhancing customer commitment to

PaaS, and increasing consumer acceptance and willingness to pay for remanufactured products within the PaaS framework. Additionally, this level includes advocacy efforts through industry associations to promote necessary policy shifts that support remanufacturing and the broader adoption of the PaaS model.

The capacity development tools are presented in Figure 5.

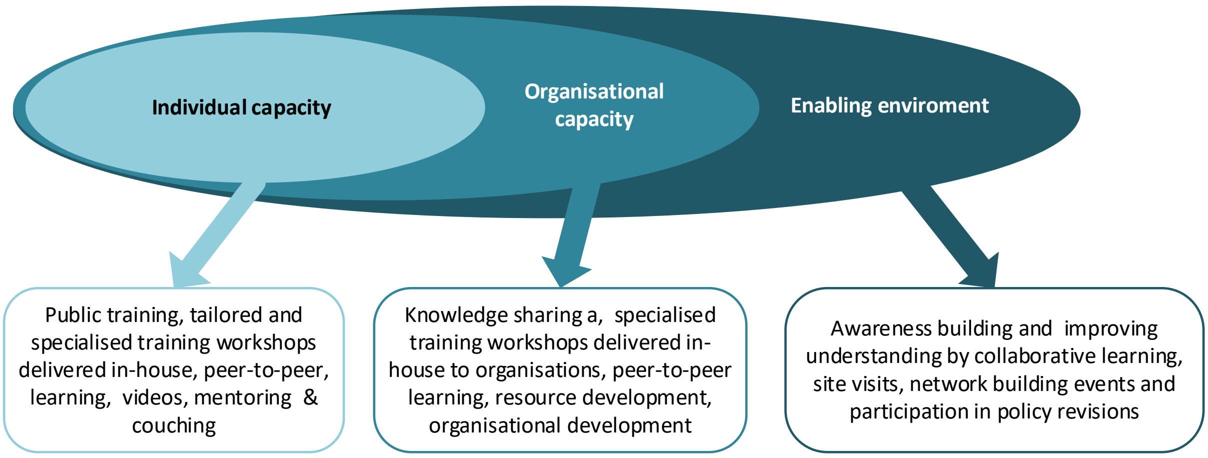

Figure 5 - Capacity development tools developed based on (Brown et al. 2001; Clearwater 2024)

The capacity development tools:

- *Training and Education* (Public or Customized Programs): Delivering targeted learning opportunities to enhance specific skills and knowledge, ensuring competency development across relevant domains. These programs integrate collaborative learning approaches, such as peer discussions, interactive workshops, and cross-functional training, to facilitate knowledge exchange and practical skill application on remanufacturing, in particular on the non-distractive disassembly and quality assessment.
- *Mentoring and Coaching*: Providing structured guidance and support from experienced employees to facilitate knowledge transfer on remanufacturing and PaaS, skills enhancement, and professional development. This approach encourages collaborative learning through personalized feedback, shared experiences, and continuous learning networks.
- *Resource Development*: Ensuring access to essential tools, equipment, and resources required to strengthen capacity and enhance operational efficiency in remanufacturing.
- *Organizational Development*: Enhancing internal structures and processes, including management strategies, communication frameworks, and human resource management systems, to improve overall organizational effectiveness. Awareness-building strategies are embedded within organizational change efforts to cultivate a shared understanding of best practices, industry trends, and the benefits of continuous improvement.
- *Partnerships and Networking*: Establishing collaborative alliances with organisations, institutions, and communities to foster resource-sharing, knowledge exchange, and collective problem-solving. These networks serve as platforms for collaborative learning, enabling the dissemination of best practices and fostering a culture of continuous improvement. Additionally, strategic partnerships contribute to awareness-

building efforts, increasing stakeholder engagement and promoting broader adoption of circular business models.

Testing of Rem-Cap-Up

The Rem-Cap-Up model was preliminarily tested using data obtained from three case studies, involving the mapping of disassembly processes—both destructive and non-destructive—as well as the remanufacturing process. In cooperation with the industrial partner, the washing machine was analysed as a 'use case' to test the framework.

We follow the logic of the cascading model for circular economy by Kircherr et al. (2017). It is assumed that both the OEMs and the WEEE recycler will move from a recycling scenario through Component-as-a-Service (part harvesting strategy), then refurbishment and finally to remanufacturing. Therefore, the choice of companies A-C reflects this logic. The characteristics of the three case studies are summarised in Table 1. Based on the data from the case studies the detailed assessment tools were developed.

Table 1- Case studies characteristics

Company name	A	B	C
Type of company	OEM	Disassembling company	Recycling & reuse company
Size of company	big	small	medium
Products/cores	EEE (household alliances)	EEE ICT and household appliances	WEEE general
Organisational level aim	Development of PaaS with R strategies	Moving from disassembly and repairs to contracted remanufacturer	Extending the existing R end-of-life and end-of-use services
Individual level focus	Building awareness for circular business model, developing knowledge &skills for PaaS with R strategies	Building awareness for PaaS Development of remanufacturing knowledge & skills	Building awareness for circular business model, developing knowledge &skills for PaaS with R strategies
Company representatives	Strategic, tactical level	Strategic level (business owner), operational level	Strategic (business owner), Tactical, Operations level
Data collection and triangulation	PaaS Business model development workshops Experts survey	Expert interviews Process observation Process mapping Process modelling & simulation	Expert interviews Process observation Process mapping Remanufacturing process development workshops Process modelling & simulation

From the point of view of conservation and reuse of critical raw materials, two processes were identified as critical for further capacity building compared to current practices. During the site visits, the current destructive dismantling was analysed to identify the gap in terms of required skills, process and resource changes. The non-destructive disassembly and the inspection/quality assessment process were identified as the key activities to scale up remanufacturing in PaaS for the critical raw materials and to make it economically viable and environmentally friendly remanufacturing in combination with recycling (as the ultimate end-of-life scenario). The design of the remanufacturing process was further supported by LogABS simulation software to optimise workflow of process.

For the purpose of capacity building, the tools were developed to address both organisational and individual capacity levels. At the individual level, different assessment tools were developed for three groups of employees: operational, tactical, and strategic. The capacity gap was assessed based on responses to a structured questionnaire that measures the difference between reference level 5 (lean and green remanufacturing in the PaaS), and the current capacity level. Although the assessment framework maintains six consistent areas and more than 20 categories (as presented in Table 2), specific capacity requirements vary by hierarchical level, ensuring a customised assessment approach. The separate set of questions is designed for each group of employees (operational OpQ1- $OpQn_i$; tactic TaQ1- $TaQn_i$; strategic StQ1- $StQn_i$), in six common areas and more than twenty categories. The assessment scheme includes a set of questions with yes/no answers, which are later translated into the scores:

- Level 1: no awareness, no knowledge, no experience
- Level 2: limited awareness, basic knowledge, minimal experience (training phase/supervision needed)
- Level 3: intermediate awareness, practical knowledge, intermediate experience
- Level 4: high awareness, specialised (practical and theoretical) knowledge, significant experience
- Level 5: full awareness, expert knowledge, extensive experience (expert)

Table 2 - Example of the assessment scheme for the strategic level

Code	Capacity	Awareness					Knowledge					Experience				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
P1	Increasing durability and quality of key components to support remanufacturing															
P2	Implementing product design for remanufacturing & easy disassembly															
P3	Reviewing the current design of EEEs in B2C suitability for remanufacturing															
P4	Technological innovations in EEE impact the cost effectiveness of remanufacturing															
P5	Applying IoT technology in remote assessment of products															
L1	EcoDesign to support modularity for reducing remanufacturing costs															

Code	Capacity	Awareness					Knowledge					Experience				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	and achieving economies of scale															
L2	Adopting Circular Economy Action Plan (2020) with PaaS model as a key enabler of the circular transformation															
C1	Ensuring quality standards in the remanufacturing process to increase customers' willingness to purchase remanufact. products															
C2	Providing access to product's functionality without the traditional sales															
C3	Using PaaS model to support customer loyalty towards the brand															
B1	Measuring the impact of the complexity of disassembly, and that easy, non-destructive disassembly processes and comparing the ease of disassembly in manual, robotic, and human-robot collaboration operations															
B2	Using tools such as LCA/LCC for calculations in PaaS															
PR1	Retaining ownership and control over the products, to benefit from the information on product returns (quantity, quality, and timing)															
PR2	Monitoring the necessary qualifications to perform the remanufacturing process															
PR3	Developing non-destructive disassembly															

Code	Capacity	Awareness					Knowledge					Experience				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	related to the remanufacturing process to bring economic benefits															
PR4	Optimising the maintenance and service costs															
PR5	Comparing the materials and energy saving for end-of-use scenarios to achieve environmentally viable recovery of EEE products															
PR6	Assessing the remanufacturing cost in comparison to residual value of products															
PR7	Using non-destructive disassembly related to the remanufacturing as a source of cost-effective spare parts for servicing and maintaining products during PaaS															
PR8	Aiming for economy of scale for remanufacturing															
SC&RL1	Assessing core quality depending on time and user return behavior, and EEE regulations (may require recycling instead of remanufacturing).															
SC&RL2	Calculating additional costs related to collecting used products from customers, sorting, remanufacturing them, and delivering to new customers under future contracts															
SC&RL3	Assessing competition from recyclers and other value recovery providers (VRPs) in the context of economies of scale															
SC&RL4	Improving collection and transportation															

Code	Capacity	Awareness					Knowledge					Experience				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	methods of (W)EEE to prevent damage and enhance their suitability for remanufacturing															
SC&RL5	Building partnerships in (W)EEE collection to support optimal recovery options in PaaS—such as remanufacturing, repair, reuse, or recycling—and to determine whether to handle remanufacturing in-house or outsource															
SC&RL6	Developing proactive core management															
Legend: P - products; L - legislation; C - customers & market; B - servitised business model; PR - remanufacturing process 7 technology; SC&RL - supply chain and take-back system																

The strategic level refers to senior manages and business owners. These areas are assessed separately also for operational, tactical employees two separate assessment forms, following the same logic as in Table 2. The company can analyse the results both separately for each level or as a cumulated gap value.

The capacities at the organisational level are measured in the same six areas and categories but using a different measurement tool. An exert from this tool for assessing organisational capacities is presented in Table 3. The assessment framework consists of a set of yes/no questions, which are subsequently translated into the corresponding scores:

- Level 1: Lack of resources, remanufacturing process, and business strategy incorporating circular practices.
- Level 2: Fragmented resources, informal remanufacturing process, and a partially developed business strategy with some adoption of circular practices.
- Level 3: Dedicated resources, repeatable remanufacturing process, and a clearly defined business strategy integrating circular practices.
- Level 4: Dedicated resources aligned with the PaaS model, formalised and repeatable remanufacturing process within the PaaS framework, and a business strategy that incorporates circular practices through the PaaS model.
- Level 5: Fully dedicated resources within the PaaS model, with a strong focus on Lean and Green solutions; repeatable, formalised processes optimised remanufacturing for Lean and Green principles within the PaaS model; and a business strategy that systematically supports continuous improvement and innovation within the PaaS and circular economy framework.

In the assessment tool for the organisational level of capacity building, all areas and categories are applicable.

Table 3. Examples of the assessment scheme for the organisational level.

Code	Capacity	Resources					Process					Circular Strategy				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
P1	Assessment of the durability and quality of key components for remanufacturing															
P2	Assessment of whether the product design allows for non-destructive disassembly of the product															
P3	Implementation of the remanufacturing process that takes into account the product structure															
P4	Assessment of the cost-effectiveness of remanufacturing in terms of the technological innovation of the product															
P5	Assessment of the durability and quality of key components															
L1	Design EEE for remanufacturing and modularity to reduce costs and achieve economies of scale.															
L2	Implementation of circular practices (remanufacturing, refreshing, repair)															
C1	Implementation of quality standards in remanufacturing to increase customers' willingness to purchase regenerated products															
C2	Offering access to product functionality without traditional sales															
C3	Providing PaaS model to support customer loyalty towards the brand															
B1	Evaluation of remanufacturing efficiency based on disassembly complexity, highlighting easy, non-destructive processes for EEE, and using tools to compare															

Code	Capacity	Resources					Process					Circular Strategy				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	manual, robotic, and human-robot disassembly															
B2	Calculation of enviromental and economic benefits by using tools like LCA/LCC															
PR1	Retaining product ownership and control to leverage data on returns (quantity, quality, timing).															
PR2	Development of human resources to perform remanufacturing															
PR3	Development of economically viable, non-destructive disassembly methods for remanufacturing															
PR4	Development of economically viable maintenance and servicing in PaaS															
PR5	Assessment of material and energy saving potential for economically and environmentally viable recovery of EEE															
PR6	Assessment of remanufacturing costs in comparison to the product's residual value															
PR7	Development of non-destructive disassembly in remanufacturing to provide cost-effective parts for servicing in PaaS															
PR8	Development of economy of scale in the remanufacturing process															
SC&RL1	Assessment of core quality based on return timing and user behavior, with some EEE subject to regulations that may direct them to recycling instead of remanufacturing															
SC&RL2	Assessment of additional costs related to collection, transportation, sorting, remanufacturing, and															

Code	Capacity	Resources					Process					Circular Strategy				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	delivery of used products under subsequent contracts															
SC&RL3	Mitigating competition from recycling and other VRPs.															
SC&RL4	Development of WEEE collection practices that minimise damage during transport to preserve remanufacturing potential															
SC&RL5	Development of partnerships for WEEE collection to support remanufacturing															
SC&RL6	Development of proactive core management for an efficient remanufacturing process															
Legend: P - products; L - legislation; C - customers & market; B - servitised business model; PR - remanufacturing process 7 technology; SC&RL - supply chain and take-back system																

The results allow a company to identify the capacity gap in the context of the development of an economically viable and environmentally friendly remanufacturing process in PaaS. Visualisation of the capacity gap is presented in Figure 6.

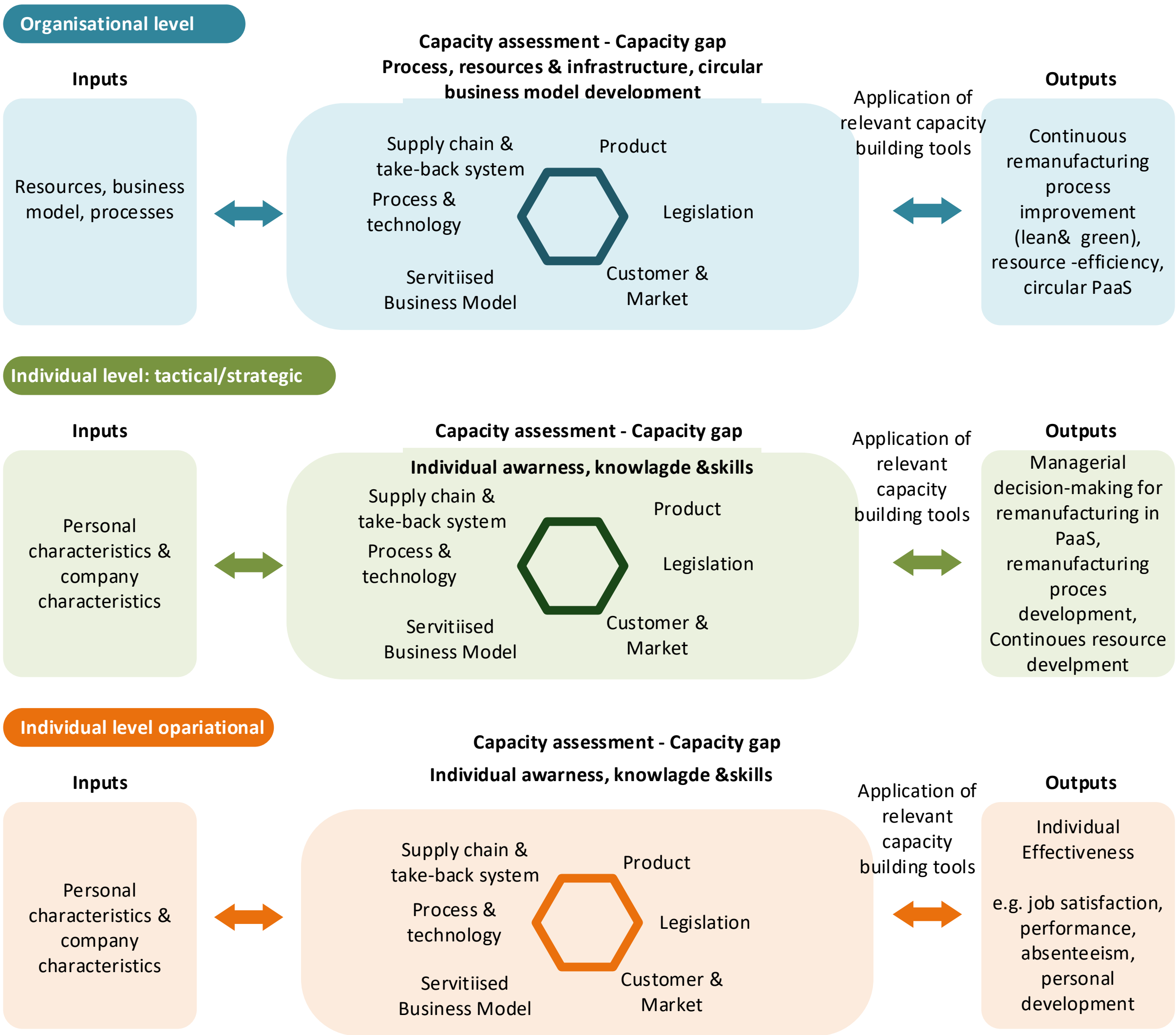

Figure 6 - Identification of capacity gap

The results for each level are presented using radar charts, which show the measurement tool's ratings for each area and category on a scale of 1 to 5. The difference between the maximum rating of 5 and the actual rating represents the gap within a given category. This approach provides a clear and user-friendly visualisation of the measurement results. A similar visualisation method has been proposed by other researchers, such as e.g. Kurilova-Palisaitiene et al. (2024). The results are then used to identify and apply the relevant capacity building tools, as shown in Figure 5.

Conclusions

This paper presents a novel model Rem-Cap-Up which aims to support companies to scale up remanufacturing in PaaS for electrical and electronic equipment. In this article, we explore the challenges and enabling factors for scaling up remanufacturing in PaaS models, with a particular focus on electrical and electronic equipment (EEE) in consumer (B2C) markets. Currently, there is a significant gap between small-scale pilot projects implemented by OEMs and the desired state where remanufacturing within a PaaS model becomes a standard business practice for consumer goods such as household appliances. Despite the growing interest in circular business models, there is a lack of academic research that provides evidence-based recommendations for scaling up EEE remanufacturing in consumer markets within a PaaS framework. Existing studies are fragmented and industry adoption remains limited. To address this knowledge gap, we combined findings from a systematic literature review with expert insights from industry case studies. The final outcome of this study is the development of a capacity building model for practitioners, designed to provide structured guidance on overcoming challenges and activating key enablers for circular transformation. This model serves as a decision support tool, equipping industry professionals with practical tools and strategies to facilitate the large-scale implementation of remanufacturing in PaaS business models. We combined an integrated perspective of remanufacturing activities—encompassing product design, remanufacturing processes, value chain management, and customers.

The main limitation of this study lies in the small availability of real-world cases on EEE remanufacturing within PaaS models, which constrained the development of the capacity-building model. While the proposed model is based on insights from a systematic literature review and expert input, the lack of extensive industry implementation cases limits its empirical validation. To address this gap, we incorporated expert surveys and feedback from SCANDERE project partners to strengthen the model's applicability. The proposed Rem-Cap-Up is build based on the challenges and enablers which are typical for the EEE sector. The scalability of the proposed solution to other sectors is feasible after an initial verification of the compatibility of challenges and enablers. The model is designed for the EU legal framework under the WEEE Directive. Thus, the questions in the assessment tool may need to be adapted to meet other legal requirements. However, the general logic of the assessment tool's development can be easily transferred to other sectors and regions with only minor adjustments.

Future research will focus on extending the empirical base of the capacity building model by testing the relationships between the six categories in capacity building in fuzzy or grey multi-criteria decision-making techniques. We will also investigate the effectiveness of capacity building tools for industrial cases in different categories of equipment with high CRM content and high potential for circularity.

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