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Concept for the design method SCANDERE, Deliverable 4.3

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1. Introduction

As previously indicated in the project proposal, the process of designing Product-as-a-Service (PaaS) should prioritize the optimization of technical, economic, social, and environmental aspects, taking into consideration the criticality of the raw materials utilized. However, there is a notable absence of a design approach for developing a PaaS offering from a business model perspective, which is essential for achieving an economically efficient PaaS business model. An earlier study underscores the importance of emphasizing value over traditional mechanical product functionalities (Brissaud et al., 2022). Consequently, PaaS design necessitates distinct procedures compared to those typically employed in conventional product design.

To enhance PaaS design, a pivotal factor lies in improving the flow of information. There is a pressing need to create and disseminate systematic methods for capturing information and knowledge across the entire lifecycle, transitioning between products and services seamlessly. Currently, there exists a divergence in proposed design methods, necessitating guidance on selecting the appropriate method for specific situations, as well as establishing connections between these methods across various phases of the lifecycle. Additionally, there is a demand for novel techniques that can accommodate the dynamic nature of PaaS, addressing uncertainties and risks associated with demand and supply requirements.

This second deliverable of IPG for the SCANDERE 18-month project report is the development of the design method, taking advantage of our expertise in the field of sustainability assessment methods. For this deliverable, there has been close collaboration with all the project partners, most especially with KUL and PUT to develop the model for the whole lifecycle, including remanufacturing and recycling insights from WP5 and WP6.

2. Methodology

Circular design encompasses a multifaceted approach that incorporates activities such as sharing, repairing, reusing, refurbishing, remanufacturing, and recycling. These strategies serve as catalysts for the perpetual circulation of products, components, and materials within the economic ecosystem. This paradigm shift transcends the conventional product-centric model by embracing the concept of "product-as-a-service," extending product lifespans, and elevating the practice of upcycling materials. As a result, the circular design fosters continuous circulation, contributing to the economy while mitigating waste and promoting sustainability.

Henceforth, product design within a circular economy necessitates a shift from the prevailing product-centric design approach to a more comprehensive system-oriented design strategy. However, executing such a multifaceted transformation demands a fundamental shift in mindset, as elucidated by Medkova and Fifield (2016) and the RSA (2013). The overarching objective is to achieve optimal functionality over numerous lifecycles while concurrently upholding their enduring economic viability, as supported by den Hollander et al. (2017), Linder et al. (2017), and Sumter et al. (2018).

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The landscape of product design implementation assumes a pivotal role within the context of a circular economy. Product developers and designers wield substantial influence over the entire lifecycle of products (see Figure 1), significantly impacting their environmental consequences and overall performance, as emphasized by McAloone and Pigosso (2018). Consequently, various tools have been developed to assist designers, particularly in the initial design phase, encompassing both tangible and emotional aspects.

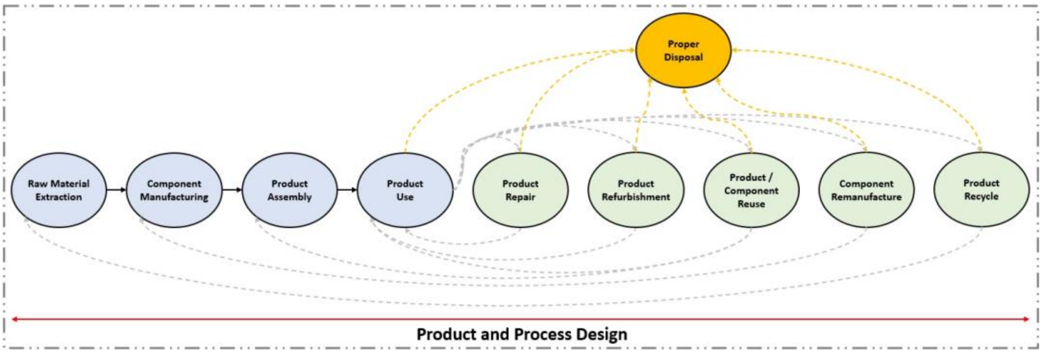

Figure 1. The role of design in the products lifecycle.

Preliminary research pertaining to product and service design for circularity reveals that the tangible product dimension includes aspects such as design for durability, design for standardization and compatibility, and design for disassembly and reassembly, and for the intangible service dimension, the design for maintenance and repair, and the design for upgradability and adaptability in the case of services. Hence, it becomes imperative to establish comprehensive guidelines for both product and service-oriented design, steering designers toward the objectives of a circular economy. This mandate is substantiated by the works of Blomsma et al. (2019), Heyes et al. (2018), and Mendoza et al. (2017).

Our design method (Figure 2) intends to cover both tangible and intangible dimensions considering the design of product-as-a-service offers for different electric and electronic equipment. Our **hypothesis** for the method development is that PaaS requires to step into the design process from a **value-capturing** perspective (rather than from a function specification). In the forthcoming era of Product-as-a-Service, customers will increasingly seek specific outcomes, product performance, and the utility derived from product usage, alongside a positive experience encompassing economic, environmental, and social sustainability aspects (Brissaud et al., 2022). Nevertheless, the perception of value by users remains a subjective aspect, potentially influenced by cultural differences, behavioral intentions, and socio-demographic characteristics. This subjective appreciation of value is dynamic and likely to evolve throughout the entire duration of PaaS implementation. As different consumer segments engage with PaaS offerings, their preferences and priorities regarding product qualities will surface across multiple iterations of value propositions and user experiences. This iterative process will enable product designers to integrate both user anticipations and feedback, leveraging data, information, and expertise to enhance the design and functionality of products in response to user needs and expectations.

Since PaaS shall sell value instead of a product or of a function, a **business model** perspective is at the heart of our method. An understanding of the business model simplifies the process for a company to effectively harness and orchestrate all the essential prerequisites for transforming from product-selling-centric approaches to solution-offered-oriented strategies, through the implementation of service-centric business models (Adrodegari et al., 2016). The **Business Model Canvas (BMC)** situates the **value proposition** at its core, affording a comprehensive perspective of the business proposal (van Loon and van Wassenhove, 2020). This enables companies to scrutinize and assess their market position.

Original Equipment Manufacturers (OEMs) interested in transitioning from their traditional linear business model to a Product as a Service approach will initially need to integrate some of their existing products into the new business model. This integration, in its initial stage, may limit the scope of product redesign. Both the linear and the PaaS business models will **coexist** during this transition phase, with the majority of resources being sourced from the traditional linear model.

However, it is important to note that solely focusing on the servitization of products from the linear manufacturing approach does not guarantee a reduction in the use of critical raw materials or yield environmental benefits. To make the PaaS model more sustainable in the early stages of this transition, products must remain in active use for longer period of time and with different users over their lifecycle. The **circular economy** (CE) can support the reduction of overconsumption of natural resources while delivering economic benefits (Kirchherr et al., 2018), and **circular business models** (CBMs) are recognized as key levers in boosting the CE transition. CBMs are based on the principle of product economic value retention (Linder and Williander, 2015) and seek to improve resource efficiency by keeping products and components longer through efficient middle and end of life processes. This underscores the significance of **value retention processes** (VRPs) as enablers of circularity. Value retention processes, such as **reuse**, **repair**, **refurbishment** and **remanufacturing** are key to maintain product viability.

In the latter stages of the product's lifecycle, parts remanufacturing, and **recycling** (parts harvesting included) becomes pivotal for the continued viability and environmental sustainability of the PaaS business model. This is because components that are in good condition or have undergone remanufacturing or refurbishment can be incorporated into the repair of other PaaS products. This practice not only cuts costs, but also extends the lifespan of the products.

Furthermore, the integration of recycled materials, including plastics and critical raw materials, into the traditional linear manufacturing process plays a crucial role in diminishing the requirement for fresh raw material extraction. This approach contributes to the conservation of valuable resources and reduces the environmental impact associated with resource extraction.

Nevertheless, **circularity enablers** face many known **challenges**, such as rudimentary recycling, low willingness of customers to use refurbished or remanufactured products (Zhou and Yuen, 2020), a limited market for secondary electrical and electronic (EEE) products (Bovea et al., 2017), among others. And, the majority of design strategies state modular design, design for disassembly, repair, disassembly and remanufacturing, however, these are mostly seen from a technical view and they don' take into account process design considerations that could lead to achieve circularity in a PaaS scheme.

To **overcome** these challenges from a **total design point of view** that is **business model driven**, our design method consists of three sections. The first section is the inner circle in blue colour, that represents the cycle to create design guidelines in order to develop or improve a PaaS business model. This cycle is represented as closed retrofitting loop that counts with four steps: 1) PaaS business model development/improvement, 2) Enforcing circularity, 3) Challenges recognition, and 4) Design guidelines. The second section adheres to the framework proposed by Taka et al. (2020), visually distinguished in purple, comprising four foundational elements capable of configuring a financially advantageous and appealing proposition while concomitantly establishing resource loops conducive to sustainability. The initial pair of pillars (Close the loop and Improve the loop) center their attention on the material dimensions of the Circular Economy (CE), facilitating the closure of material loops and encompassing all pertinent facets of environmental sustainability, such as product longevity and the avoidance of hazardous substances. The subsequent pair of pillars (Monetise the loop and Excite the loop) adopt a business-oriented perspective, emphasizing the monetization of circular solutions, fostering user enthusiasm, and considering potential incentive mechanisms. The third and final section, three circles in different shades of green, uses the three spheres of sustainability (society, economic, and environment) concept. The impacts of every taken cycle need to be tested in terms of the three spheres.

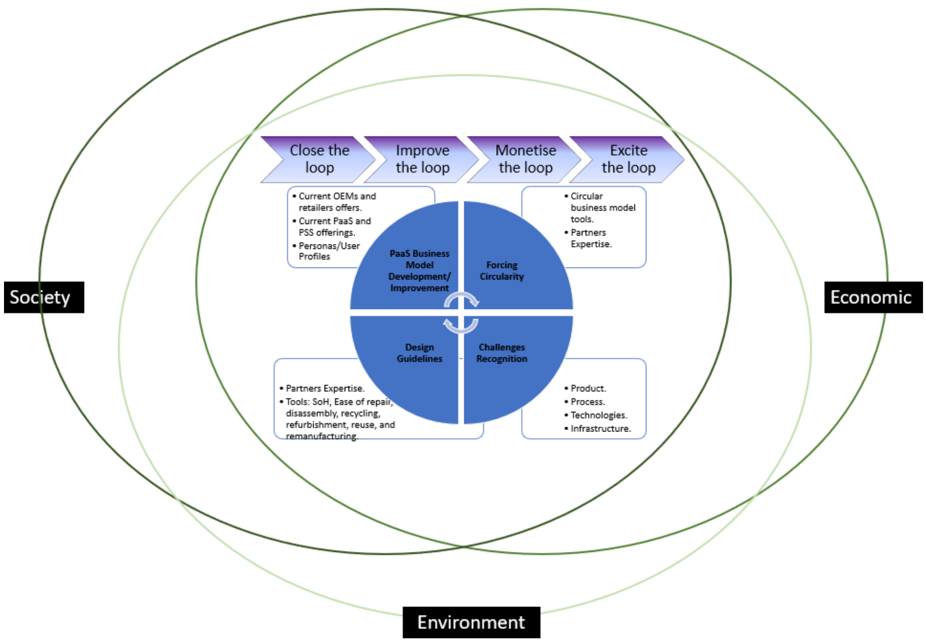

Figure 2. The design method (Based on Taka et al., 2020).

In order to accomplish this method, IPG has organized three working meetings with the SCANDERE partners. These three meetings helped to develop the first section of the design method, which is the four-step cycle for the development of a PaaS business model.

- First Meeting Objectives: 2023-08-22 / 10h00-12h00 / Zoom
  - Presenting the methodology used by IPG to develop the work.
  - Presenting two abstract ideas for CIRP LCE and CIRP Design 2024 and asking for interest in collaboration.
  - Presenting and discussing the types of personas, leasing business models, and design implications found by IPG.
  - Presenting and discussing two types of business model examples for short and long-term contracts.
  - Discussion and decision on two or three types of personas for short, medium, and long-term types of contracts.

- Second Meeting Objectives: 2023-08-22 / 10h00-12h00 / Zoom
  - Presenting the business model implications by the partners according to their expertise.
  - Discussion and decision on the final business models for the case of vacuum cleaners.
  - Presenting the business model for the component-as-a-service offering of the batteries.
  - Discussion on the battery's offerings.

- Third Meeting Objectives: 2023-08-22 / 10h00-12h00 / Zoom
  - Presenting, discussing, and deciding the final business model proposal after the first two meetings on the vacuum cleaner.
  - Presenting and discussing the critical analysis of the implementation of any circular business model for EEE by every partner with their main challenges.
  - Discussing the necessity of a fourth meeting.
  - Explanation of possible tasks before the fourth meeting.

A fourth meeting is planned for November 24th, 2023. Every partner is asked to collect their thoughts based on literature and experience on the main challenges/barriers for forcing of the circularity from their specific task point of view in terms of product 1) product, 2) service ecosystem, 3) New/Digital Technologies, and 4) Infrastructure. Additionally, each partner shall propose from their specific perspective, what can be done in terms of design (product, service, technology, and infrastructure) to alleviate these challenges/barriers:

  - PUT: Reverse Logistics (Take back) and Remanufacturing.
  - KUL: Recycling, Reuse, Refurbishment, and Repair.
  - LiU: Revenues, costs, positive and negative impacts: in this case, this shall address the challenges/barriers that make the measurement of costs and revenues, and positive and negative

impacts difficult for a PaaS model. And how can design (of the product, service, technology, and infrastructure) help improve these measurements.

This will allow us to define all the challenges in terms of reverse logistics, recycling, reuse, refurbishment, repair, revenues, costs, and positive and negative environmental impacts. Additionally, this meeting will deliver design guidelines in terms of product, service, technology and infrastructure.

Once all the challenges identified and design guidelines proposed, subsequent smaller meetings will help group the challenges and design guidelines into the pillars of section 2. Lastly, the use of tools such as life cycle assessment, critical raw materials efficiency, life cycle costing, and social life cycle assessment will donate the designer the impact of the different choices and allow them to make decisions. Following subsections will demonstrate the work done to this day with the completion level percentage in parenthesis.

2.1. Design Guidelines Creation Cycle (80%)

2.1.1. PaaS business model development/improvement for EEE (100%)

The trend of amalgamating products and services to provide novel and more fitting solutions is on the rise among enterprises, particularly in the backdrop of a fiercely competitive global market (Mont, 2002). This transition necessitates a shift from a product-centric orientation to a service-centric methodology (Meier et al., 2010). Consequently, a PaaS framework amalgamates physical products and services within a unified operational system. This circumstance compels us to contemplate the concurrent design and development of services and tangible products, presenting fresh challenges in contrast to product-centric methodologies. Additionally, through the design and enhancement of services, there is an expansion of the portfolio encompassing both goods and services, fostering a more intimate rapport with end-users (Mathieu, 2001).

The achievement of a company is contingent upon its operational strategy and networks (Schuh et al., 2009), signifying the paramount importance of reconfiguring the business model (BM) to underpin the provisioning of PaaS. Consequently, it becomes imperative for a PaaS to concurrently contemplate the amalgamation of both business and technical facets within its models (Zou et al., 2019).

Following a concise examination of the existing literature (Garcia Lechuga et al., 2023; Krummeck et al., 2022), it becomes apparent that the Business Model Canvas (BMC) enjoys widespread recognition as an effective tool for facilitating the design process of Product as a Service (PaaS). Consequently, the BMC assumes a pivotal role in the PaaS design endeavor.

The Business Model Canvas (Osterwalder & Pigneur, 2013) can aid manufacturers in the transformation and progression from their conventional salescentric paradigm to the development of a Product as a Service (PaaS) model, consolidating essential components throughout its design phase (Wallin et al., 2013). This framework offers companies a structured framework for cataloging their prevailing market offerings within the context of the PaaS approach.

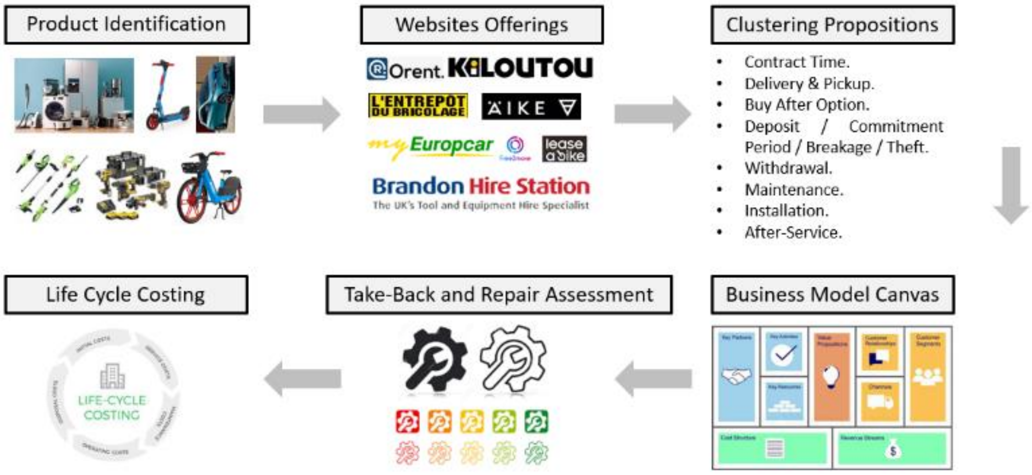

Figure 3. EEE PaaS offers Development Process.

This stage was divided into 6 steps (Figure 3):

- Selection of EEE.
- Screen current market offers.
- Group the offers into market offers.
- Develop BMCs for the clustered offerings.
- Assess the impact of product take-back and repairability on the developed canvases.
- Assess the Life Cycle Costing of the developed canvases.

➢ As a **first step**, four types of EEE were chosen for the analysis: home appliances, do-it-yourself tools, gardening tools, and electric mobility (scooters and bikes). The reasons behind this decision were: (1) most of these products incorporate electrical or mechanical components to achieve their intended functions, (2) they serve utilitarian purposes and are designed to perform specific tasks or functions, (3) they require user interaction to achieve their purpose, (4) they require maintenance, cleaning, and occasional repairs to ensure they function correctly and have a longer lifespan. For these reasons, these products have the most opportunities to be offered in a product-as-a-service context.

➢ The **second step** was the market analysis of current offers for the studied EEE other than buying. During the data collection and data analysis for the products, different retail and manufacturer websites from both Europe and North America were scrutinized. The market analysis can help identify the industry dynamics, such as globalization, entrepreneurship, and technological advances

(Slater & Olson, 2002), and, understand the value propositions already offered (both product and service perspectives).

In the process of collecting and analyzing data related to these products, a comprehensive review of various retail and manufacturer websites in both the European and North American regions was conducted. Google search engine was used with the criteria of finding offers of the PaaS business models. A total of fourteen websites were scrutinized: 5 for home appliances, 2 for DIY tools, 1 for gardening tools, and 6 for mobility. One important thing to mention is that out of the 14 websites, only two were both manufacturers and service providers of the EEE, the other 12 acted as retailers with no influence on the manufacturing of the product.

- The **third step** was the grouping of the offers based on similar characteristics, such as value propositions and key activities and resources. Based on the types of E&E products analyzed, the different offers were clustered and the types of business models identified.

Once all websites were analysed, some common characteristics were observed on the value propositions. Customer information normally available on the websites included: contract time, delivery and pick & up, buy after option, deposit necessary, commitment period, breakage and theft rules, withdrawal information, installation and maintenance services, and after-use service. Two types of offers where found for the studied EEE: subscription and pay-per-use. Subscription includes the provision of the product for a defined period of time, going from days and weeks (normally for DIY and gardening tools) to months or years (normally for home appliances). Pay-per-use is the most used for mobility products where the customer pays for the service of using the device for a short period of time going from minutes to hours.

- The **fourth step** was developing a generic business model canvas on the identified business models from the market offerings. This tool allowed to bridge the gap among crucial elements that interact together within a system (Hamwi et al., 2021). Once all the business models were identified, we realized that all offers had already been analyzed in the literature. To develop the BMC, both literature and internet databases were reviewed, and as a result, general business model propositions were delivered.

For the BMCs development, the authors went into existing literature on the identified PaaS offerings from both scientific and web sources. For the case of subscription offer, a total of three articles were identified (Nyvall et al., 2022; Arrigo, 2021; Kalair et al., 2021) and for the case of pay-per-use offer a total of four (Koop et al., 2021; Papí and San Román, 2020; Vitkauskaitė and Vaičiukynaitė, 2020) articles were reviewed. The information obtained can be reviewed in Table 1.

- The **fifth step** was to perform a take-back and repair assessment on the proposed business models. An essential consequence arising from the transition towards service-oriented models is the redefined role of reverse logistics and repair integrated into the novel business paradigm.

From the point of view of the assessment of take-back system when developing the PaaS Business Model, there are crucial elements to consider, most notably:

- Definition of entry points to take-back-system; centralized or decentralized possibilities to return product, e.g., using e-Commerce or brick and mortar channels);
- Pre-assessment of the state-of-health of products to avoid unnecessary transportation (e.g., products which are suitable only for recycling shall be directly sent to the recyclers);
- Cost-effective and environmentally friendly transportation (e.g., avoiding unnecessary transport);
- Storage of products to avoid damage and environmental burden;
- Visual inspection and final decision on VRPs;
- Quality assurance and repacking;
- Redistribution/transportation for the next PaaS.

The implementation of subscription or pay-per-use models might generate more transportation and other logistics activities than linear sales models. In order to avoid this, it is necessary to provide the assessment of the take-back system and related logistics operations (e.g., collection form customers, transportation to the repair facilities, storage in-between contracts) (Golinska et al., 2023). The Relog matrix (see Fig.4) is an easy tool to follow the design of the PaaS with subscription or pay-by-use models for EEE, as it allows to identify gaps which need to be addressed when iterative developing the canvas business models.

Processes	PaaS provider Resources & Know-how			Outsourcing Resources & Know-how		
	L	M	H	E	N	A
Planning of collection from customer				Y/N	Y/N	
Visual pre-assessment				Y/N	Y/N	
Sorting at the collection				Y/N	Y/N	
Packing at collection				Y/N	Y/N	
First mile-transportation				Y/N	Y/N	
Storage of used products				Y/N	Y/N	
Visual inspection & check lists for VRPs				Y/N	Y/N	
Repair and servicing				Y/N	Y/N	
Quality check & repacking				Y/N	Y/N	
Last-mile transportation				Y/N	Y/N	

Fig.4. Relog-matrix

The traffic light analogy is used to identify problematic (in red, L- with low resource and/or know-how availability), awareness (in yellow, M- with medium resource and/or know how availability), and well-developed (in green, H-with medium resource and/or know-how availability) areas in processes being performed in a take back system for PaaS. When the red /yellow area is identified it is a signal that in the iterative process an existing (marked E – in Fig.2.) or new partners (marked as E – in Fig.2) should be included for the development of a take-back system in PaaS. The last column in Fig.2 marked, as [132] reflects the additional actions/resources which are needed to be identified when iteratively developing Canvas Business model.

In the context of repairability, both subscription and pay-per-use models yield comparable advantages, primarily attributed to the core characteristic of both models: the product's ownership remains with the Original Equipment Manufacturer (OEM). Consequently, the responsibility for product maintenance and upkeep does not shift to the consumer, a departure from the conventional linear sales model. When assessing these two models concerning repair aspects, it is imperative to examine usage patterns within each.

The pay-per-use model offers incentives for less frequent product use, while simultaneously encouraging more comprehensive utilization during each usage session. For instance, consider a washing machine leased under the pay-per-use model, which may yield fewer total washing cycles compared to a machine in the same environment leased through the subscription model and influence the user's washing behavior, for example, incentivizing reduced washing temperature by charging more for cycles at higher temperatures [37]. However, since each washing cycle carries a fixed cost, users are inclined to maximize each cycle's capacity, potentially resulting in greater wear and tear per cycle as customers seek to optimize their resource utilization.

An additional differentiating factor pertains to the duration of product use under each model, significantly influencing the product's handling, utilization, and consequently, its propensity for repair and the condition in which it is returned. Another important gap in the literature is the lack of methods for assessing reparability, especially for mechanical products [38]. The pay-per-use model, characterized by shorter rental periods, is more likely to experience less diligent treatment, potentially necessitating more frequent repair interventions. Conversely, the subscription model typically involves longer lease durations, fostering a sense of responsibility and care among consumers, thus mitigating the frequency of repair requirements.

- The **sixth and final step** was to perform a Life Cycle Cost (LCC) on the proposed business models. LCC analysis has been observed to enhance companies' comprehension and awareness of specific challenges they encounter, thereby facilitating the development of knowledge and competencies necessary to surmount these obstacles.

When financially assessing business models, it is important to scope the LCC with the same functional unit and system boundaries, otherwise the results are not comparable (Kambanou and Sakao, 2020). As such, fairly comparing the business models in Table 1 is challenging without access to large amounts of reliable data. Therefore, for the rough LCC presented in this research in supporting the case company, the focus lies in showing how the LCC support in the business model development. Figure 5 illustrates the profitability of the business-as-usual (Sales) business model compared to three PaaS proposals. Here, all values are discounted relative a time-based discount rate, and the sales values are for comparability distributed equally over the PaaS contract length through equivalent annual cost (EAC).

Through this approach, the value proposition of the PaaS business models could easily be tweaked allowing the LCC to provide the direction for further development. For example, A and B provide lower profitability than the business-as-usual, meaning that to not lose on the PaaS adoption, further adjustments are necessary. Meanwhile, the varied monthly profitability of A relative the same total profitability of B, is likely to enable dynamic value propositions that promotes loyalty, feeling of inclusiveness, or higher contract flexibility.

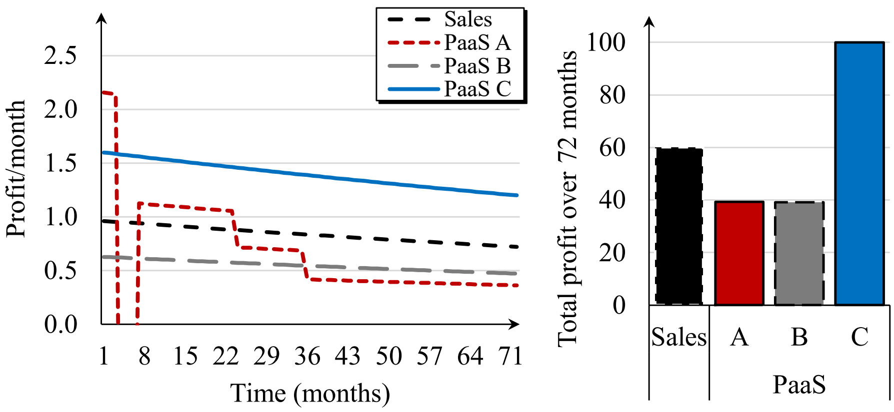

Fig.5. A rough LCC of three PaaS business models in relation to the business as usual (Sales).

2.1.2. Enforcing Circularity (70%)

Incorporating circularity into both product and service design is pivotal for the establishment of more sustainable systems. Under this paradigm, products and services should be conceived right from their inception to minimize their environmental footprint throughout their entire lifespan. This entails assessing their impact not only during their initial usage phase but also anticipating subsequent phases, such as resale, remanufacturing, or repair, aimed at prolonging its operational life. Designing for circularity necessitates the integration of novel foundational design principles and a profound understanding of the materials employed.

Harmonizing business models with the concept of circular value creation is acknowledged as a fundamental pathway for advancing the achievement of the globally embraced Sustainable Development Goals (SDG), which have garnered unanimous support from 193 nations (Schroeder et al., 2019). An integral facet of circular business models (CBM) revolves around the sustenance of value even beyond a product's end-of-life stage. This can be accomplished through methods such as extending a product's operational lifespan (e.g., repair, reuse, refurbishment, and remanufacturing) or by closing the material loops (e.g., recycling), as elucidated by NuBholz (2018).

In this context, the suggested design methodology entails active participation from project collaborators to delineate the requisite tasks, essential organic, energy, and technical resources, critical partners, expenditures, and the environmental and social repercussions indispensable for fostering circularity within the realm of product-as-a-service propositions for EEE. This perspective emphasizes elements like take-back (reverse logistics), reuse, refurbishment, repair, remanufacturing, and recycling as shown in Figure 6.

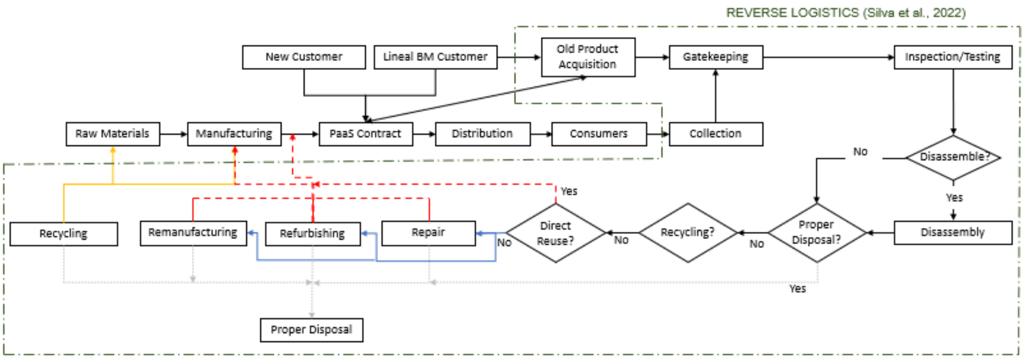

Fig.6. Necessary activities to force circularity.

A critical analysis of the elements of any circular business model that will implement short/medium/long-term PaaS to EEE were done during the third meeting and this activity will be finished during the fourth one. Every partner was asked to answer the following questions according to the area of their expertise:

Which additional activities are necessary to force circularity?
Which organic resources are needed?
Which technical resources are needed (infrastructure, equipment)?
Which energy resources are needed? Could the activity be energy-neutral?
Which key partners/suppliers/human resources are necessary for the circularity?

Based on this information:

What are the costs involved?
What are the environmental/social impacts?

During the third meeting we only received the information from PUT, KUL is still missing, and the social and environmental impacts from LiU also.

2.1.3. Challenge recognition (70%)

In this context, primarily a literature review was used to identify the main challenges, barriers and design implications for EEE from the point of view of repairing, reusing, refurbishing, and remanufacturing, and recycling, since as shown before, there is no information available in terms of PaaS. Literature was searched in Scopus and Web of Sciences with the same first and second search words EEE, electrical, electronic, E&E, challenges, barriers, design, and design implications as shown in Figure 7. Only papers from last five years were screened (> 2019), and as a third search, different keywords on repair, recycle, remanufacture, refurbish, and reuse gave a total of 5,394 papers. A total of eight RIS files were downloaded in total from both search engines.

Following, ASReview Lab was used to screen titles and abstracts of all the eight files. ASReview tool was chosen because it uses machine learning to support the finding of relevant publications in a more efficient manner (ASReview, 2022). In ASReview, the screening is still conducted manually, but it is supported with machine learning by reordering the records according to relevance scores that are modelled via the previous choices of the reviewer. At this stage, the criterion chosen was to stop reviewing once 20 consecutive irrelevant papers. Excel files were after exported from the software and fused in one having a total of 113. Duplicates were eliminated with the Excel tool, leaving a total of 76 papers. As a next step, introduction and conclusion of the papers allowed to reduce the total number to 32. Finally, other 12 papers were added in the review through co-occurrence, and after whole text read, a total of 28 papers were included in the review.

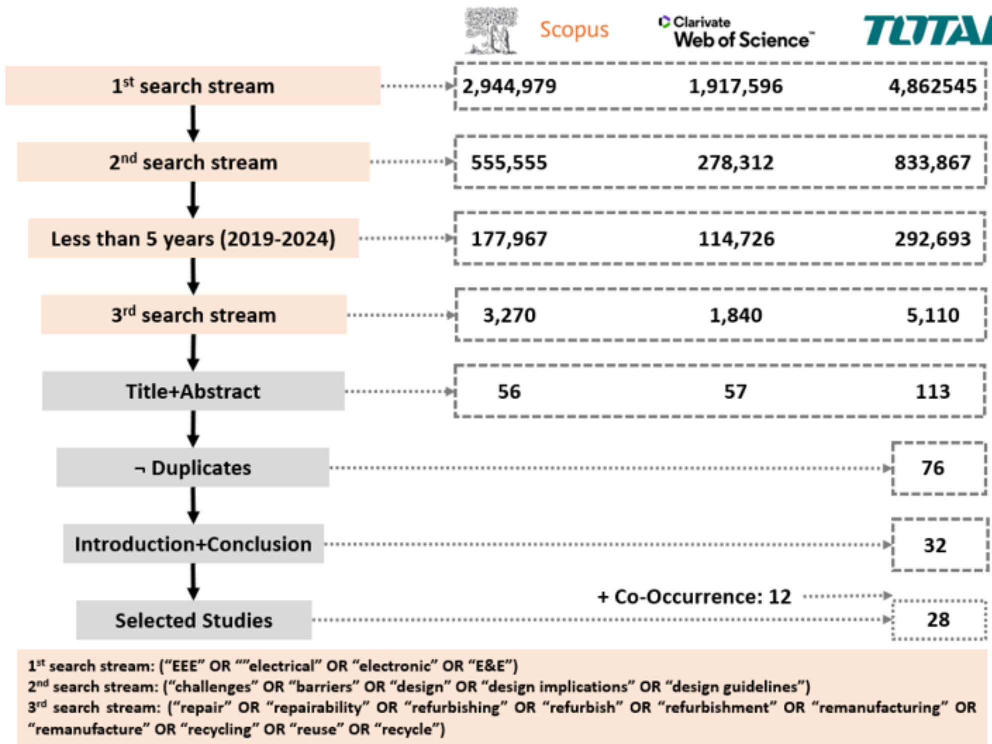

Fig.7. Literature review.

Table 1. Identified challenges to force circularity into PaaS business model offers (References available in CIRP Design Paper).

Challenges	Design Guidelines
C1. Product Obsolescence.	C14. Quality concerns of harvested parts.
C2. Repair charges.	C15. The need for large storage facilities.
C3. Lack of spare parts or access to them.	C16. Lack of skill from designers
C4. Lack of access to appropriate infrastructure.	C17. Lack of information
C5. Return flow volume.	C18. User Profiles/Customer behaviors
C6. Technical/Skilled labor availability.	C19. Intellectual property
C7. Cost and time.	C20. Taxation.
C8. Returning products in varying conditions.	C21. Low quality materials and components of the product.
C9. Consumer mistrust.	C22. Lack of disassembly without destroying the product.
C10. Legal and regulatory obstacles.	C23. High heterogeneity of e-waste.
C11. Market cannibalization.	C24. Increased competition in the recycling, refurbishment, and remanufacturing.
C12. Poor quality performance of repaired, reused, refurbished, or remanufactured products.	C25. Poor separability of components and composites that contain CRMs.
C13. Optimal disassemble level	C26. Lack of possibility of fully automated processes.

These challenges need to be validated and extended with the challenges found in the activities necessary to force circularity that weren't found in the literature.

2.1.4. Design Guidelines (70%)

For the design guidelines, the process of challenges identification mentioned also in subsection 2.1.3 allowed to obtain different design guidelines from the literature review (see Table 2). These design guidelines combined with the necessary activities to force circularity will bring a final list of different items.

Table 2. Identified design guidelines to force circularity into PaaS business model offers (References available in CIRP Design Paper).

Challenges	Design Guidelines
D1. Try to use digitalization, ICT and IoT solutions	D13. Provide manuals and documentation.
D2. Make the product and components easy to inspect.	D14. Make spare parts and exchanging components easily available.
D3. Make the product and components easy to clean.	D15. Use joints and connectors that can be easily opened and closed several times
D4. Make exchanging of faulty components easily accessible.	D16. Minimize the use of different incompatible or dissimilar materials.
D5. Make it easy to dismantle/disassemble the product non-destructively	D17. Enable access and removal of hazardous or polluting parts.
D6. Use of renewable materials.	D18. Use of material combination and connections that allow easy liberation
D7. Use of recyclable and secondary (recycled) materials.	D19. Enable upgrade design features
D8. Consider toxicity and other environmental aspects of materials.	D20. Flexibility of products with parts and interfaces that fit other products.
D9. Standardized components across different products and models.	D21. Extended warranty.
D10. Standardized tools across different products and models.	D22. Ease of handling and storage
D11. Durable and robust components and materials.	D23. Minimize the number of materials.
D12. Modular construction.	D24. Exchange CRMs for other alternatives.

The final step is to create an excel format, where all the items (challenges and design guidelines found in literature and through the meetings with the partners will be located in the first column and in the second to sixth column, three options will be given (1. Not important, 2. Moderate important, 3. Highly important) to measure the relevance of each item in terms of reuse, repair, refurbishment, remanufacturing, and recycling. The format will be after sent to the different expert partners on the previously mentioned topics involved in the Scandere project. Partners will be asked to answer the level of importance on the total items for the five categories thinking from a PaaS perspective. Average values on the importance of the items will then be calculated.

To help make the decision on whether a product should go into reuse, repair, refurbishment, remanufacture or recycling, some concepts will serve as tools to make the decision: repairability index, state of health, ease of repair, ease of disassembly, ease of remanufacturing, and critical raw materials. Information on all these concepts is presented in the following subsections.

➢ Repairability Index

Repairability plays a key role in almost all circular processes, and more particularly in the Pass offer than in the sale of products. Insofar as it has been used, it provides insight into a product's ability to be repaired, taking into account the entire ecosystem surrounding the repair operation itself. Examples of ecosystems include the business proposition, accessibility and availability of spare parts, accessibility and availability of support, interfaces, documentation and so on.

The more repairable a product is, the lower the maintenance costs, and the greater the uptime of the product in a PaaS offering. We have started a project on the design of an agile repairability tool that can be used flexibly to assess the repairability score of different types of products such as mechanics or EEA. To achieve this, we defined three main stages.

The first step was to compare existing methods and summarize existing criteria in a manufacturing conference paper that is about to be published. The second step is to validate the influence of these criteria on product repair by means of a questionnaire addressed to mechanics/EEAs experts from different backgrounds. An industrial mechanics/EEE expert, a normative mechanics/EEE expert, a mechanics/EEE expert researcher, and an industrial mechanics/EEA technician.

After the criteria validation stage, we plan to use an AHP method to assign the weight of each criterion in calculating the final reparability score. The third step is to apply this calculation method to different types of products. This reparability tool has a dual value for the design phase and for promoting circularity. It is a parameter that can help decide whether the used product has the capacity to be remanufactured, recycled, reused, reconverted or resold, etc. In parallel with the above-mentioned ongoing work on reparability, we are seeking to demonstrate that the reparability score should not only be assessed for a new product, but also for a used one.

In this way, it will contribute to the transformation of users' mentalities, which is the objective of the ecological transition. In this way, a PaaS model can be based on a threshold value of the reparability score to make the decision to take back a product for repair or maintenance in order to avoid a failure or service shutdown.

This study is being carried out in tandem with the development of a method for assessing the state of health of products to promote the circular economy.

➢ State of Health

The state of health of a product provides information on the degree of degradation of the product in its current state compared to its initial state. Two conference papers have been published on CIRP LCE (Wandji et al., 2022a) and EUROSPI (Wandji et al., 2022b) on this notion.

Assessing the state of health of a product is not an easy task, as it requires data on the state of the product and data analysis skills to train a machine learning model and ultimately be able to interpret the result. Today, it's still difficult to find data for assessing a product's state of health, because it's expensive and may require changes to the product's design. However, a great deal of data on electric vehicle batteries is available online. But it's almost the only data.

In any case, an analysis of the literature shows that the number of articles on SoH is growing all the time. This demonstrates the importance of this concept. Our aim is to propose a standard and flexible method for assessing the SoH of a product in a circular context. With this in mind, we are defining a way of monitoring this type of information using the IoT, for example. As far as circularity is concerned, we are working on defining a SoH threshold value that could help manufacturers make a decision on what direction to take a used product at the end of its life. This study should include KPIs such as the reparability index, the remanufacturing index, the recyclability index, the upgradability index, etc., which describe the product's capacity to be circular. Here's what we have in common with the method of calculating the reparability index for the product's use phase. Similar work should be done for the calculation of other KPIs.

➢ Ease of repair and refurbish

Ease-of-repair/refurbish becomes critical in sustainable design because it allows a product to be functional throughout its life cycle rather than having to go through a complex reverse logistic process and take-back systems (Huang, 2016). Sabbaghi et al. (Sabbaghi and Behdad, 2017a, 2017b) discovered that encouraging repairability via providing manuals or repairing information, among other things, had a positive impact on future purchases of repairability products. Furthermore, the expense of repairing the goods may not be considerable for the users. Product warranty, on the other hand, should be considered while making maintenance decisions (Yeh et al., 2007).

➢ Ease of disassembly

Product lifetime extension options including repair, reuse, and product harvesting for component reuse all necessitate easier access to product components. As a result, it is critical to define requirements for the ease of disassembling both housing components in order to improve access to internal components for inspection, maintenance, and repair, as well as disassembling commonly failing and valuable components in order to facilitate repair by replacing failed components and recovering components for reuse or remanufacturing. Disassembly is critical but difficult compared to assembly due to varying product states, orientations, missing parts and/or product information, and lower lot sizes as products frequently return over time (Huang et al. a, 2019; Huang et al., 2021).

➢ Ease of remanufacturing

All operation phases, such as inspection, disassembly, reprocessing, reassembly, and testing, must be considered when adapting items for remanufacturing (Sundin and Bras, 2005). It is important to remember that the primary purpose of remanufacturing is part reuse. As a result, if a part cannot be reused as-is or after repair, the ease of cleaning or reassembly has less value in terms of remanufacturing (Yang et al., 2015). This means that a lot of work might be put into product design without getting the full benefits.

➢ Critical raw materials

The increasing scarcity of specific raw materials has emerged as a significant concern (European Commission, 2013; Probst et al., 2016). EEE typically contains elevated levels of conventional metals alongside lower concentrations of critical raw materials (CRMs) in various composite forms. CRMs play an indispensable role in advancing innovative high-tech applications. The European Commission identifies a total of 30 CRMs (European Commission, 2020), and within this classification, the EEE sector serves as the final destination for 13 of these materials (Esenduran et al., 2020). Existing e-waste recycling methodologies prove insufficient in targeting the CRMs typically present in EEE, primarily due to their limited concentrations (Ilyas et al., 2017).

Fortunately, there are mitigating activities that may be taken to address the issues associated with the EU CRMs dependence. The first is a replacement. Some CRMs can be replaced with less critical alternatives. However, because to the unique qualities of CRMs used in specific applications, this is not always viable. The second option is to improve component performance. That means using less material and consequently fewer CRMs.

2.2. Business Model Patterns (30%)

Once we have identified all the activities from the circular business model workshops, together with the challenges to achieve them and the design guidelines to obtain them. As can be seen in figure 8, there are different items included in each pillar of the business model patterns, later on the challenges and design guidelines will be located in the pillars to understand where in time they should be faced or used by the designer.

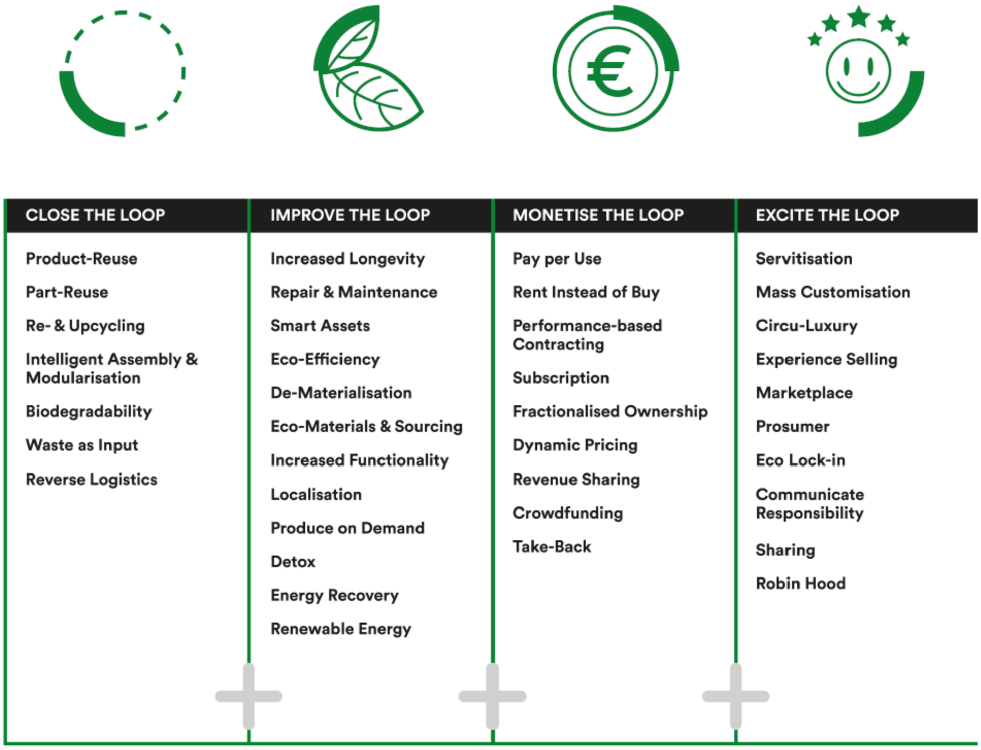

Fig.8. Business model patterns.

2.3. Three Spheres of Sustainability (0%)

Lastly, our design method finds that the proposed design guidelines studied can support a range of activities within the business model patterns. To select the appropriate design decision, we will use the three spheres of sustainability, society, environment, and economics, to demonstrate the impact of the decisions on the three spheres. For this matter, life cycle assessment, life cycle cost analysis, and social life cycle assessment will be used to define the total sustainability impacts.

3. Dissemination

IPG plans to disseminate the knowledge from this deliverable through three papers sent to two different conferences. Two abstracts have been sent and accepted by CIRP LCE 2024 in Turin, Italy, June 19-21, and one additional abstract has been sent and accepted by CIRP Design 2024 in Cranfield, UK, June 3-5.

3.1. An exploratory study for product-as-a-service (PaaS) business models and life cycle costing for electric and electronic products.

Manufacturing enterprises continue to grapple with transitioning from their existing business model, which revolves around designing and selling tangible products, to a novel approach centered on providing a blend of products and services. The concept of Product-as-a-Service (PaaS) emerges as an innovative business strategy capable of catalyzing this fundamental shift. However, effecting changes in operational methodologies and value delivery mechanisms is imperative, consequently prompting modifications in the core business frameworks of these companies. In light of this context, the objective of this study is to discern and categorize prevailing market alternatives pertaining to electric and electronic (EEE) products, excluding conventional purchasing methods. Additionally, the study endeavors to devise PaaS models from the ground up. These proposed PaaS models are intended to furnish a comprehensive business model canvas and insights into life cycle costing implications. This foundational information forms the essential groundwork for undertaking a case study aimed at proposing a fresh business model founded on the principles of the PaaS strategy, specifically tailored for EEE products. The chief contribution of this endeavor lies in its ability to aid companies during the initial stages of shaping a PaaS strategy. This assistance is extended through the demonstration of diverse PaaS business model designs along with an exploration of their associated costs.

3.2. Enforcing circularity: challenges and design implications of Product-as-a-Service (PaaS) business model offers for electric and electronic products.

The move towards a circular economy brings a range of practical challenges for product and service designers that will need to facilitate this transformation from a linear take-make-dispose model to a more circular model. The concept of Product-as-a-Service (PaaS) emerges as an innovative business strategy capable of catalyzing this fundamental shift. In a PaaS context, any product will be used by several different users during its lifetime through different operational methodologies and value delivery mechanisms, so incorporating circularity into both product and service design is pivotal for the establishment of more sustainable product-service systems. To force circularity, it is imperative to be able to close loops in the current PaaS offerings through means of reverse logistics (take-back), reuse, refurbishment, repair, remanufacture, and recycling. However, different challenges arise from each of them which translate into different design implications. With the help of the literature and through a cooperative ERA-MIN project, different expert partners will donate their insides to the challenges to design a PaaS offering for electric and electronic (E&E) equipment. The objective of this paper is to present the main challenges found and describe the design implications derived from them.

3.3. Parametric LCA integrating a product's State of Health: A decision-making tool based on environmental impact in the context of circular strategy.

The state of health (SoH) of an end-of-life product is one of the levers for optimizing the circular economy (CE) process in order to allow the product life extension. Many approaches have been developed in the literature to estimate the SoH of a complex system (CS). In this study, we asked ourselves the following two questions: First, how to optimize the circular lifecycle scenarios of the components of a product at its end of life? And second, how to estimate the SoH of a product at the end of its life? To answer these questions, we proceeded as follows. First of all, the state of health of a product needs to be considered as an important parameter as well as performance or reliability. To estimate the SoH, it is necessary to identify the product parameters to be observed. The problem here is to choose the most relevant parameters among all those available for a CS. To do this, we have proposed a conditional-based maintenance approach (CBM) which consists in establishing the fault tree of a product. It consists of functionally breaking down a product into its various components and identifying the main failures for each of them. Then, these failures are used to identify the parameters to be monitored. Second, based on the most relevant parameters, the health indicators needed to estimate the SoH of the product are obtained. Then, the Prognostic and Health Management approach (PHM) is proposed in order to estimate the SoH. In the objective of providing a general solution that could be used for estimating the health status of any product, we have proposed a generic framework for the PHM approach. It serves as a guide in choosing the right approach according to the situation. Then, we proposed a decision-making strategy to optimize the process of orienting components in circular loops. This strategy is based only on the technical-functional indicator, which is the SoH of the components. Finally, we showed an example of the implementation of the proposed method for the case of the electrical scooter motor.

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