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Sustainable and Green Electronics for Circular Economy

Deliverable 4.7

Review on the design and implementation prototypes of circular business models in Sustronics

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Management Summary

Deliverable **D4.7** reviews the **design and implementation of circular business model (CBM) prototypes** developed within the **Sustronics** project across **10 pilots** spanning health technology, lighting, and automotive sectors. It documents:

- The **theoretical background** on CBMs, circular economy strategies, CBM archetypes, and LCA integration.
- Development and application of a **CBM Design Template** used consistently across pilots.
- Detailed **CBM descriptions per pilot**, structured along value proposition, delivery, creation, capture, and circular economy strategies.
- Synthesis of **CBM archetypes** in three product categories.
- A **KPI-based review** of CBMs, aligned with TRL levels and early product development realities.

The deliverable provides strong empirical grounding (22 interviews, 7 workshops), bridges **business model thinking and LCA**, and contributes novel **health-technology-specific CBM archetypes**.

List of abbreviations

CBM	Circular Business Model
DPP	Digital Product Passport
ECG	Electrocardiography
EEG	Electroencephalography
IGTS	Image Guided Therapy Systems
ISO	International Organization for Standardization
IVD	In-Vitro Diagnostics
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
OEM	Original Equipment Manufacturer
PaaS	Product-as-a-Service
TAU	Tampere University
TRL	Technology Readiness Level
WEEE	Waste Electrical and Electronic Equipment

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1. Introduction

1.1. Purpose of the document

The purpose of this document is to review the circular business models (CBMs) that were developed for each of the pilots in the Sustronics project, as a result of the work done in Task 4.5. CBMs were developed for each pilot to guide development of the pilots in making sustainable choices while remaining profitable. By considering CBMs at the lower TRL stages, the largest sustainability impact can be made, because most of the design choices are still open. In this document, the entire process from making the CBM templates up to reviewing the CBMs is described. Chapter 2 starts with a literature review about the use of CBMs in industry and integration of lifecycle assessments for the development of CBMs. From there CBM design templates were developed that were used to build a CBM for each pilot. The process and considerations made for creating the templates are described in Chapter 3. Each of the pilots developed a circular business model, which are presented in Chapter 4. From these CBMs four archetypes CBMs were extracted. Chapter 5 describes the method and results of the CBM review, followed by a discussion on the results.

1.2. Related documents

- Circular business models described in this deliverable are based on the pilots developed in WP3. The deliverables from WP3 (D3.1-D3.4) contain detailed descriptions of the pilots.
- D4.4 describes detailed end-of-life concepts that can be incorporated into circular business models.
- D4.5 describes the eco2-design framework, which integrates sustainability in product design processes. The defining and development of the circular business models are part of this process.
- D4.6 contains lifecycle assessment strategies that can be used as input for circular business model development.
- D5.9 contains the exploitation plans for each pilot, based on the circular business models.

2. Background literature

This section provides the conceptual background for the work conducted within the Sustronics project. It introduces circular business models (CBMs), circular economy design strategies, and CBM archetypes relevant to the health technology sector. The section also explains the role of Life Cycle Assessment (LCA) in CBM development and positions the project's work in relation to existing research. In doing so, it clarifies the knowledge gaps addressed through the development and use of the "CBM Design Template" and the identification of CBM archetypes.

2.1. Circular business models, circular economy design strategies, and circular business model archetypes in the health technology sector

CBMs describe how organizations create, deliver, and capture value while reducing resource use and environmental impacts across full product life cycles. Unlike linear models, CBMs integrate circular economy principles such as product life extension, material recovery, and more efficient use of product and service systems across key value dimensions, including value proposition, value creation and delivery, and value capture (Bocken et al., 2016; Geissdoerfer et al., 2018). CBMs are operationalized through circular economy design strategies that guide how circularity is implemented in practice. In addition, specially tailored CBMs are crucial for the health technology and electronics industries because the products are complex, used in medical and healthcare applications where the functionality needs to be flawless, and are required to follow strict rules and hygiene standards. These conditions affect how reuse, refurbishment, service-based access, and material recovery can be implemented. In electronics-intensive sectors, these strategies address environmental impacts at different stages of the product life cycle, including manufacturing, use, and end-of-life management.

The health technology sector presents specific challenges for CBM implementation due to regulatory, hygiene, and safety requirements associated with electronic and clinical products. These conditions influence which circular strategies are feasible and how they can be applied. For example, reuse of certain components is restricted in the health technology sector due to regulatory and hygiene requirements. Design approaches such as modularity, refurbishment, and material recovery play a more prominent role in circular business models. These approaches require alignment between environmental objectives and regulatory and operational requirements (Guzzo et al., 2020; Ishaq et al., 2024; Kane et al., 2018).

So-called CBM archetypes describe generalized configurations of CBMs identified across multiple firms and application contexts (Bocken et al., 2016; Pieroni et al., 2020). These archetypes describe how circular strategies are organized across CBM value dimensions, including value proposition, value creation and delivery, and value capture. In the Sustronics project, CBM archetypes tailored specifically for the health technology sector provide a basis for comparing circular business practices across the Sustronics project pilots and for clarifying the influence of health technology sector-specific constraints on CBM development.

2.2. Integration of life cycle assessment in circular business model development

A LCA is a standardized method for assessing environmental impacts across product life cycles (ISO 14040, 2006; ISO 14044, 2006). In CBMs, LCA supports the evaluation of circular strategies by identifying environmental hotspots and assessing whether impacts are reduced or shifted across life cycle stages (Böckin et al., 2022).

A LCA informs CBMs by enabling comparisons between circular options such as reuse, refurbishment, and recycling and by supporting sustainability-related value propositions (Centobelli et al., 2020). In service-oriented CBMs, environmental assessment can focus on delivered functionality rather than individual products (Parolin et al., 2024). In practice, LCA integration with CBM development can remain limited in the early stages of product and service development due to restricted data availability in early design phases, limited organizational expertise, and difficulties in linking environmental results to CBM value dimensions (Bjørnbet and Vildåsen, 2021; Böckin et al., 2022). These challenges are often evident in heavily regulated sectors such as health technology, where confidentiality and regulatory requirements further constrain data access. In the health technology sector, particularly for medical devices, regulatory frameworks focus on patient safety, infection prevention, and conformity assessment. Environmental considerations and related information disclosure receive comparatively less attention, and detailed information on product composition and manufacturing processes may remain confidential. This can restrict the availability of data required for LCAs (Arun Kumar, 2021; Hoveling et al., 2026).

2.3. Contribution of the Sustronics project and identified research gaps

Research on CBMs and LCA provides limited empirical evidence on how life cycle thinking is applied in business model development within the health technology sector (Awasthi et al., 2019; Ertz and Patrick, 2020; Reike et al., 2018; Teece, 2018). Existing studies tend to address environmental assessment and business model design as different research topics, which limits insight into their interaction during strategic planning and early product and service development phases.

This Deliverable addresses these gaps through empirical work carried out across 10 pilots in the health technology sector. Qualitative data were collected through 22 interviews and 7 workshops (online / in-person) with project partners. This work enables an analysis of how circular design strategies and environmental considerations are addressed across the CBM value dimensions, including value proposition, value creation and delivery, and value capture. Based on this analysis, the project developed a “CBM Design Template” that provides a consistent basis for documenting and comparing the CBM value dimensions applied in the pilots and for identifying distinct CBM archetypes that are applicable across pilots (Lüdeke-Freund et al., 2019).

The identified CBM archetypes are linked to circular economy design strategies focused on extending, cycling, and intensifying resource use. These strategies are assessed in relation to the three pillars of sustainability, namely environmental, economic, and social benefits. This assessment supports a consistent evaluation of CBMs in early development phases, where detailed quantitative LCA data are often limited due to the low level of design maturity and data confidentiality requirements.

This report provides a structured contribution to understanding how CBMs, CBM archetypes, and life cycle thinking can be integrated within the health technology, lighting and automotive sectors.

3. Circular business model design template

This section describes the methodological approach applied in this report to analyse CBMs across the project pilots. The work is grounded in qualitative research method and builds on systematic data collection and analysis to support consistent examination of circular business practices in the health, lighting and automotive technology sectors.

The standard Circular Business Model (CBM) Canvas template adopted by Tampere University (TAU) was employed as the conceptual framework within this project. The template provides a consistent and structured basis for data collection and analysis across the 10 pilots. It supports the systematic examination of how CBMs are conceptualized and how sustainability and environmental considerations are incorporated into business decision-making processes within the different technology sectors. For clarity and consistency throughout this deliverable, this “Circular Business Model (CBM) Canvas template” is hereafter referred to as the “CBM Design Template”.

Transitions toward a circular economy are driven by business models that differ from traditional linear approaches by integrating circular economy strategies such as reuse, refurbishment, service-based offerings, and material recovery. Prior research underscores the role of business models in enabling circular practices, as they define how value is proposed, created, delivered, and captured across product life cycles and value dimensions (Bocken et al., 2016; Geissdoerfer et al., 2018; Lüdeke-Freund et al., 2019; Osterwalder and Pigneur, 2010).

In this project, the “CBM Design Template” developed by TAU provides the framework for collecting and analyzing qualitative data across the ten pilots. The CBM design template specifies the structure for describing business practices and for comparing patterns across cases. Its use provides consistency across the pilots and reflects sector-specific constraints, including regulatory and hygiene requirements, within the analysis.

3.1. Identification of barriers and opportunities for LCA integration into CBMs

Qualitative data were collected through 22 semi-structured interviews with project partners. The interviews focused on practices, challenges, and enabling factors related to the use of LCA in CBM development. Analysis of the interview material enabled identification of the barriers and opportunities influencing LCA integration into CBMs, including regulatory conditions, organisational practices, stakeholder collaboration, market dynamics, and strategic decision-making.

Figure 1 illustrates the identified areas that influence LCA integration into CBMs, organized according to barriers and opportunities related to strategic planning and circular product design. The figure synthesizes the interview findings and provides the analytical basis for the development of the “CBM Design Template” in the next phase.

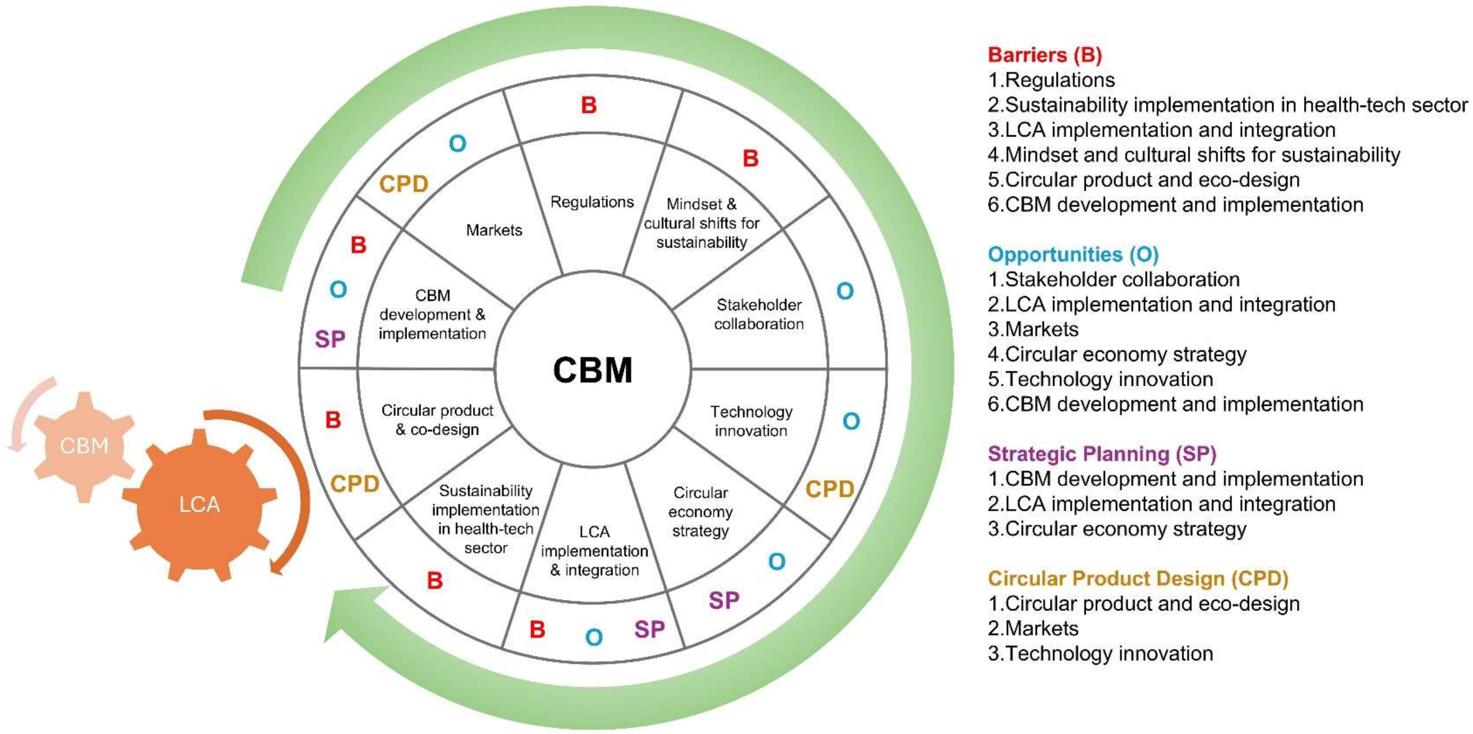


Figure 1. Identified areas that influence LCA integration into circular business models.

The analysis of the 22 semi-structured interviews resulted in findings on the integration of LCA into CBMs. These interview-based results have been submitted as a journal article titled "Sustainable Electronics in Health Technology - Using Environmental Life Cycle Assessments for Circular Business Models" (Abedi et al., 2026).

3.2. CBM design template data collection - Structure and explanation

Building on the interview findings, the "CBM Design Template" was developed to provide a structured framework for analyzing CBMs in relation to the LCA considerations that came up in the project. The template follows CBM value dimensions and includes guiding questions related to value proposition, value delivery, value creation, and value capture, as well as circular economy design strategies.

Qualitative data were collected using the "CBM Design Template" through focus group workshops with project partners. The template was first filled out during two in-person focus group workshops held on 28-30 October 2024 General Assembly (GA) in Munich, Germany. Data collection continued through seven separate online focus group workshops, conducted between January and February 2025 using Microsoft Teams. Each workshop lasted approximately 90 minutes and involved 5-10 participants, with an average of seven participants per session.

The workshops were moderated by two researchers and followed the structure of the "CBM Design Template". Discussions focused on clarifying how CBMs are described across pilots and how circular economy design strategies are reflected within CBM value dimensions. The workshop approach enabled open discussion and collective reflection, supporting refinement and confirmation of the CBM descriptions with pilot project responsible.

Figure 2**Error! Reference source not found.** presents the "CBM Design Template" including guiding questions, as used by the pilot projects during the focus group workshops.

Circular Business Model (CBM) Design Template Including Guiding Questions

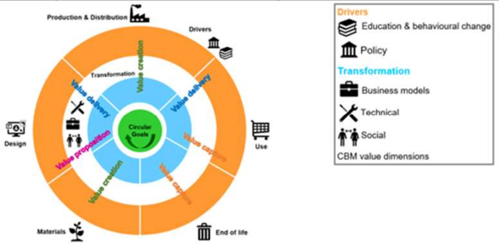
- **Product life time:________**
- **Times of use:___________**
- **Application field:_____________**
- **Cost of the product (Approx.):__________**

Circular Business Model (CBM) Dimensions

Value proposition		Value Delivery		Value Creation		Value Capture	
Products	**Services**	**Target customer & users**	**Value delivery processes**	**Key partners and stakeholders**	**Value creation processes**	**Revenues**	**Cost**
What product features make them sustainable or circular (e.g., design for reuse, recyclability, durability, modularity)? How do they address environmental challenges or customer needs?	What services can be offered to the complement the product lifecycle (e.g., repair, refurbishment)? How can these services enhance/improve the value proposition of the circular product?	Who are the key customer segments that would benefit from circular products and services? What specific needs or challenges are they facing regarding sustainability?	How do you ensure that your products or services are delivered in a way that supports circularity (e.g., through sustainable materials, packaging, distribution)? What steps can be taken to improve the delivery process to reduce waste and ensure products can be easily returned, repaired, or reused? (e.g., localisation of waste management)	Who are the main partners (e.g., suppliers, stakeholders, collaborators, waste management) that help make the circular business model possible? What roles are they required to have to create value in a circular economy?	What processes are crucial for creating value within a circular business model (e.g., remanufacturing, closed-loop supply chain) at your company or organization? How can these processes help to reduce waste and increase resource efficiency?	How can new revenue streams be created through circular models (e.g., product-as-a-service, leasing, or subscription models)? What are the opportunities for capturing value from used/recycled products or materials?	What cost drivers or factors are impacted when transitioning to a circular business model (e.g., initial investment in remanufacturing or other CE strategies)? How can circularity help reduce costs in the long-term vision?

Product life cycle stages:

1. Raw material extraction
2. Processing
3. Design
4. Manufacturing
5. Transportation / Retail
6. Use
7. End of life (EOL)
8. Disposal



Circular economy design strategies

Cycling (C)	Extending (E)	Intensifying (I)
• Refurbishing • Repair • Remanufacturing • Recycling • Reuse • Design for modularity	• Long-lasting products • Upgradability • Timeless design • Marketing and consumer education • Maintenance services • Product support/Customer service	• Rental/Leasing • Product as a service • Digital capabilites developed (e.g. tracking) • Contract management and pricing per unit of service

1. Geissdoerfer, M., Pieroni, M.P.P., Pigosso, D.C.A., Soufani, K., 2020. Circular business models: A review. Journal of Cleaner Production 277, 123741. https://doi.org/10.1016/j.jclepro.2020.123741
2. Osterwalder, A., Pigneur, Y., 2010. Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers. John Wiley & Sons.
3. Nußholz, J.L.K., 2018. A circular business model mapping tool for creating value from prolonged product lifetime and closed material loops. Journal of Cleaner Production 197, 185–194. https://doi.org/10.1016/j.jclepro.2018.06.112
4. Figure Source: OECD (2018) Business Models for the Circular Economy – Opportunities and Challenges from a Policy Perspective, RE-Circle Policy Highlight, October 2028.

Figure 2. The CBM Design Template developed for the project including guiding questions

After the workshops, the CBM Design Templates completed by the 10 pilot projects were analyzed and coded using qualitative research methods with ATLAS.ti software (without any AI assistance). This analysis enabled systematic comparison of the different value dimensions across the pilots and supported the identification and further development of CBM archetypes and related circular economy design strategies. These are presented in the following sections of this report.

The outcomes of the workshops with pilot partners have been further used to develop a scientific article focusing on the development of the CBM archetypes. The focus in the article is on the health technology sector that has the strictest regulatory requirements and is thus the most challenging sector for implementing circular business models. The article is titled “Health-Technology Industry Transitioning to the Circular Economy - Development of Circular Business Model Archetypes” (Abedi et al., 2025).

3.3. Research design and data collection process

Table 1 shows the phases of data collection and analysis, summarizing the methodological process and project implementation, from interview-based analysis to the development of the CBM Design Template and the identification of CBM archetypes through qualitative synthesis.

Table 1. Four-phase methodological and project implementation framework.

Phase	Activity	Output
1	Design of interview questions based on identified research gaps in the health technology sector related to LCA integration into CBMs	Interview questions
2	Semi-structured interviews (22 interviews with project partners)	Interview transcripts for qualitative analysis
3	Analysis of interview material and development of the “CBM Design Template”	CBM Design Template
4	Focus group workshops using the “CBM Design Template” with pilot partners	Completed CBM Design Templates from 10 pilot projects
5	Qualitative coding and analysis of completed “CBM Design Templates”	CBM archetypes and circular economy design strategies mapping

Table 1 summarizes the methodological steps applied in this work, from the design of interview questions to qualitative analysis using the “CBM Design Template”. The activities described in the table enable consistency in data collection and analysis and link interview findings and workshop-based inputs to the identification of CBM archetypes and circular economy design strategies.

4. Circular Business Models

4.1. Circular Business Models from Pilots

This section presents the CBM configurations developed across the ten pilot applications within the Sustronics project. The pilots represent diverse application fields, including image guided therapy systems, personal health devices, office lighting, embedded and wearable medical electronics, automotive components, in-vitro diagnostics, smart hygiene, and smart wound care. Despite differences in product lifetime, regulatory context, and use intensity, each pilot applies a structured CBM design template to align product development, service integration, stakeholder collaboration, and economic performance based on circular economy strategies.

The analysis of the pilots' CBM templates is organized using the defined CBM value dimensions based on business development literature: value proposition, value delivery, value creation, and value capture, complemented by circular economy design strategies including extending, cycling, and intensifying. For each pilot, the tables included below summarize how the product and service elements are configured, how value is delivered and created across the product life cycle, how financial viability is addressed, and which circular strategies are practically applicable given pilot-specific technical, clinical, and hygiene requirements.

Across the pilots, different circular configurations emerge. Long-life capital-intensive equipment, such as image guided therapy systems (IGTS) and lighting systems (luminaire), emphasize durability, modularity, refurbishment, and service contracts. Consumer-oriented personal health devices combine modular product design with reverse logistics and material recovery. Wearable and embedded medical electronics, where electronic components are integrated into medical devices to enable monitoring and data collection (e.g., EEG monitoring and wearable health monitoring), prioritize sustainable material alternatives, bio-based materials, and efficient manufacturing while maintaining functionality and price levels. Hybrid healthcare solutions combine reusable electronic components (e.g., transmitters, readers, or integrated sensing units) with single-use elements such as sensor labels, patches, or wound-contact materials, enabling continuous monitoring and digital services while meeting hygiene and clinical requirements. In contrast, single-use diagnostics focus on sustainable material selection, including paper-based and biodegradable components linked to smartphone-based applications, and system-level service intensification that adds social and economic value rather than post-use material recovery and product life extension (Zhou et al., 2026).

Hence, these pilots demonstrate how circular business configurations can be adapted to different technological contexts within the health, lighting and automotive technology sectors and related domains. The following subsections provide information from the detailed CBM design templates for each pilot, outlining the interpretation of value dimensions and circular economy design strategies within their specific application settings.

4.1.1. Pilot 1.1: Green and circular image guided therapy systems (IGTS) - Low weight compact system

Table 2 shows the filled in CBM design template for Pilot 1.1, focusing on Green and circular image guided therapy systems (IGTS).

Table 2. CBM design template content for Pilot 1.1.

Green and circular image guided therapy systems (IGTS)		
CBM Dimension	**Sub-category**	**Interpretation**
Value proposition	**Products**	The product value proposition is based on material reduction of **658 kg** for the product and **552 kg** for packaging, combined with a modular and durable robotic design that enables upgrades, long use, smaller room requirements, and support for minimally invasive surgery leading to reduced time for patient hospital stay.
	Services	The service value proposition includes product take back management, repair services, and upgrades using modular tools to extend product lifetime and adapt system functionality to evolving clinical needs, supported by **20-30% faster installation**.
Value delivery	**Target customers and users**	Target customers and users include hospitals and surgery departments with sustainability targets, hospital management and procurement functions, and medical personnel who operate the systems.
	Value delivery processes	Value delivery is supported through compact shipping and reduced packaging, minimal room modification to fit existing operating rooms, reduced ceiling reinforcement, efficient room use with lower operating room waste, facilitated removal, partial reverse logistics, and reuse of systems and parts via the manufacturer or suppliers.
Value creation	**Key partners and stakeholders**	Key partners and stakeholders include a large supplier base (**Approx. 170 suppliers**), hospital construction and operating room integration partners, logistics companies, waste collection points and recyclers, and regulators shaping sustainability requirements for large European companies.
	Value creation processes	Value creation processes include modularity enabling lifetime extension, upgrades and easier refurbishment, lighter system design that reduces manufacturing and logistics footprint, reduced building material needs due to smaller rooms, and support for minimally invasive care that shortens time needed for patient recovery and hospital stay.
Value capture	**Revenues**	Revenue is captured through servicing contracts, reduced investment barriers enabled by subscription or pay per use arrangements, sales of refurbished and remanufactured products, reuse of robotic components by the manufacturer or suppliers, trade in offers supporting customer retention, and increased market share associated with sustainability benefits compared to competitors.
	Cost	Cost impacts include lower material, packaging, and installation costs, fewer room modifications, longer lifetime reducing replacement costs, and lower operational energy use with fewer operating room inefficiencies.
Circular economy design strategies	**Extending**	Product lifetime is extended through durable design, upgradability, maintenance services, customer support, and certification of lifetime extension.
	Cycling	Cycling strategies include reuse, repair, refurbishment, remanufacturing, recycling, and design for modularity to enable material recovery across product life cycles.
	Intensifying	Intensification is supported through leasing, digital capabilities such as tracking and product-as-a-service (PaaS).

The CBM design template for Pilot 1.1 presents a circular configuration for image guided therapy systems applied in the field of image guided therapy, with a defined product lifetime of 10-14 years and 10,000-70,000 procedures during the use phase. Circular value is embedded through measurable material reduction (658 kg product and 552 kg packaging), modular and upgradeable design, and service-based activities such as take back, repair, refurbishment, and reuse. Delivery processes reduce installation time (20-30% faster installation), minimize room modification, and enable partial reverse logistics. Value creation is distributed across a broad supplier base and recovery actors, while value capture combines service contracts, refurbished system sales, subscription or pay per use access, and cost efficiencies derived from longer lifetime, reduced material input, and lower operational energy demand. Together, cycling, extending, and intensifying strategies structure a circular business configuration suitable for long-life medical equipment.

4.1.2. Pilot 1.2: Sustainable system integration and product design of personal health devices

Table 3 presents CBM design template for Pilot 1.2, Sustainable system integration and product design of personal health devices. The table summarizes how product and service elements, value delivery and creation processes, value capture aspects, and circular economy design strategies are described in the CBM template completed by the pilot partners.

Table 3. CBM design template for Pilot 1.2.

Sustainable system integration and product design of personal health devices		
CBM Dimension	**Sub-category**	**Interpretation**
Value Proposition	**Products**	The product is designed for circularity through disassembly, modular architecture, replaceable critical components, design for recyclability, and the use of recycled or bio-based plastics to reduce environmental impact.
	Services	Product-related services focus on repair, replacement of critical modules, and refurbishment readiness to extend the effective use phase and lower life cycle environmental impacts.
Value Delivery	**Target customers and users**	The primary users are consumers in the personal health domain who seek sustainable grooming and beauty devices with easy repair, access to refurbished products, and proper end-of-life handling.
	Value delivery processes	Value delivery is supported through plastic-free packaging, consumer support via a help line, and reverse supply chain mapping for collection through retailers and Waste Electrical and Electronic Equipment (WEEE) recyclers.
Value Creation	**Key partners and stakeholders**	Value creation relies on collaboration between the Original Equipment Manufacturer (OEM), retailers, online platforms, distribution channels, and recycling partners to enable collection, refurbishment, resale, and end-of-life processing.
	Value creation processes	Closed-loop supply chains, parts harvesting, and material reuse processes enable waste reduction and the reintegration of recovered materials into new products.
Value Capture	**Revenues**	Revenue opportunities arise from subscription concepts under evaluation and from commercial returns and harvested parts.
	Cost	Cost impacts relate to reliance on third-party service providers, scalability requirements, and the integration of additional circular activities into the total cost of ownership, with long-term savings from reused materials and parts.

Circular economy design strategies	**Extending**	Product lifetime is extended through durability, upgradability, maintenance services, consumer education, and ongoing product support.
	Cycling and Intensifying	Cycling is enabled through repair, refurbishment, remanufacturing, recycling, and reuse, while intensifying strategies include PaaS, digital capabilities such as diagnostics and digital product passports.

The CBM outlined for Pilot 1.2 reflects a structured approach to circularity in the application field of personal grooming devices, combining product design, service provision, and system-level collaboration. With a product lifetime of approximately seven years. The model prioritizes extending the effective use phase through modular design, repair, and refurbishment while enabling cycling through closed-loop material recovery at end of life. Value is delivered to consumers via accessible repair options, plastic-free packaging, and support services, while value creation is enabled through coordinated reverse logistics and partnerships with retailers and recycling actors. The CBM integrates extending, cycling, and intensifying strategies to reduce environmental impacts and support long-term economic viability in a consumer health technology context.

4.1.3. Pilot 1.3: Sustainable luminaire

Table 4 describes the CBM design template for Pilot 1.3, summarizing the circular configuration of value dimensions and circular economy design strategies for a sustainable luminaire in the office lighting context.

Table 4. CBM design template for Pilot 1.3.

Sustainable luminaire		
CBM Dimension	**Value sub-category**	**Interpretation**
Value proposition	**Products**	The product is designed as a sustainable luminaire following eco design principles, including a modular architecture that allows easy exchange of priority parts, minimized use of glues and screws, the use of single-material components where possible, the incorporation of sustainable bio based materials, and a reduced overall amount of materials.
	Services	Service offerings focus on refurbishment, reuse of components, and light-as-a-service concepts that support extended use and recovery of value beyond initial sales.
Value delivery	**Target customers and users**	The primary target users are stakeholders and decision-makers in the office lighting segment, including developers, investors, tenants, specifiers, and installers.
	Value delivery processes	Value is delivered through adjustable luminaires, easy repair of parts, minimized and reusable packaging, and structured refurbishment projects.
Value creation	**Key partners and stakeholders**	Value creation involves collaboration with installers, e-waste collectors, recycling companies, and office-lighting stakeholders across the product life cycle.
	Value creation processes	Core processes include parts harvesting, component reuse, use of non-virgin and recycled materials, and refurbishment and remanufacturing activities.
Value capture	**Revenues**	Revenue streams are generated through light-as-a-service offerings, sales of refurbished luminaires, and service-based contracts.

	Cost	Cost efficiency is supported by reverse logistics, refurbishment and remanufacturing processes, and reduced material input through reuse and recycling.
Circular economy design strategies	**Extending**	Product lifetime is extended through long-lasting design, modularity, upgradability, maintenance services, and customer support.
	Cycling	Cycling strategies include repair, refurbishment, remanufacturing, reuse, recycling, and design for modularity to retain material value.
	Intensifying	Intensification is achieved through rental and leasing models, PaaS, and digital capabilities for tracking and contract-based use.

The “CBM design template” describes a circular approach for Pilot 1.3 in the office lighting application field, emphasizing durable product design and service-based value creation across the full product life cycle. The luminaire is designed for a product lifetime of at least 15 years and supported by modular design, repairability, refurbishment, and reuse of components. Value is delivered to office-lighting stakeholders through adaptable products, minimized and reusable packaging, and refurbishment projects, while value creation relies on collaboration with installers, recycling actors, and e-waste collectors. Revenue generation combines service-based models and refurbished product sales, supported by cost reductions from reverse logistics and material reuse. Together, extending, cycling, and intensifying strategies enable sustained functional use, repeated material circulation, and increased utilization intensity within the defined pilot application.

4.1.4. Pilot 2.1: Embedded electronics for EEG monitoring

Table 5 presents the CBM design template for Pilot 2.1, focused on Embedded Electronics for EEG Monitoring. It illustrates how the four CBM value dimensions are integrated within this pilot. These dimensions include the value proposition for products and services, value delivery and creation, value capture, and the circular economy design strategies considered.

Table 5. CBM design template for Pilot 2.1.

Embedded electronics for EEG monitoring		
CBM Dimension	**Sub-category**	**Interpretation**
Value proposition	**Products**	The EEG sensor demonstrator is designed using more sustainable materials and integrated structural electronics to reduce component count, size, and material use while maintaining existing functionality and price levels.
	Services	The value proposition includes recyclability and potential reusability of the EEG sensor enabled by design improvements, while electrodes remain disposable to meet hygiene requirements.
Value delivery	**Target customers & users**	Target customers are companies manufacturing medical electrodes, while end users include hospitals, nursing staff, medical personnel, and researchers.
	Value delivery processes	Value is delivered through sustainable and minimal packaging and through integration of electronics into mechanical parts, such as embedding electronics within plastic casings by injection molding.
Value creation	**Key partners & stakeholders**	Value creation involves manufacturers, material suppliers, and collaborations with retailers, logistics companies, and waste collection points.

	Value creation processes	Core processes include designing products, components, and materials, as well as taking back and recovering base materials from waste streams.
Value capture	**Revenues**	Revenue potential arises from cost-competitive sustainable products, increased customer appeal, and increased local value creation through EU-based production.
	Cost	Cost efficiency is supported by energy-efficient manufacturing and delivery, reduced material waste, and lower costs for recycled materials used in base substrates.
Circular economy design strategies	**Extending**	Product lifetime is supported through long-lasting product design, maintenance services, product support, and upgradability.
	Cycling	Material loops are enabled through recycling, reuse, refurbishing, repair, remanufacturing, and design for modularity.
	Intensifying	Product reusability and contract-based pricing per unit or pack support higher utilization of embedded electronics solutions.

Table 5 provides an overview of the CBM developed for Pilot 2.1, which focuses on embedded electronics used in EEG monitoring. It demonstrates how circular economy principles are integrated throughout the product life cycle, from raw material extraction to end-of-life and disposal. The pilot aims to promote sustainable manufacturing by reducing material consumption and production waste, while maintaining functional performance and cost efficiency. Although medical electrodes remain single-use due to hygiene requirements, the EEG sensor has been designed for improved sustainability and potential reuse, depending on the results of early experimental testing. The CBM template also identifies product lifetime and frequency of use as key parameters to be defined during later stages of development, reflecting the early maturity of the pilot. The application area is EEG monitoring in healthcare and research settings, where value creation is supported through collaboration among stakeholders in manufacturing, material supply, logistics, and waste management. Value capture is associated with both cost-effectiveness and increased market competitiveness of environmentally responsible solutions.

4.1.5. Pilot 2.2: Wearable health monitoring

The CBM design template for Pilot 2.2 focuses on sustainable manufacturing within wearable health monitoring, specifically medical ECG electrodes. The approach integrates sustainable material alternatives into electrode production while maintaining the same functionality and price level. As shown in

Table 6The framework (Table 6) outlines how products are developed, delivered, and economically managed across the defined product life cycle stages. It also presents the involvement of relevant stakeholders and the application of circular economy design strategies to support environmental and economic performance within the health technology sector.

Table 6. CBM design template for Pilot 2.2.

Wearable health monitoring		
CBM Dimension	**Sub-category**	**Interpretation**
Value proposition	**Products**	Demonstrators generated using sustainable materials with the goal of achieving the same functionality and the same price level as current products.
	Services	Replacing silver paste with carbon paste or copper paste and replacing PET plastics with paper or other more sustainable substrate material.
Value delivery	**Target customers & users**	Target customers are companies that are product owners for medical electrodes and use non-sustainable materials; end users include hospitals, nursing staff, medical personnel, and consumer products.
	Value delivery processes	Sustainable and cheaper solutions provided for single-use medical electrodes, which are disposed of after use to avoid contamination between patients.
Value creation	**Key partners & stakeholders**	Manufacturers, material suppliers, and collaborations with retailers, logistics companies, and waste collection points.
	Value creation processes	Designing products, components, and materials to integrate sustainable alternatives into electrode manufacturing.
Value capture	**Revenues**	In case sustainable products can be made with lower cost, it will generate revenue to the manufacturing chain of the product.
	Cost	Single-use product disposed after use; cost structure includes materials (50%), manufacturing (50%), and some energy savings when comparing carbon paste curing to silver paste curing.
Circular economy design strategies	**Extending**	Not applicable (N/A), as the medical electrode is designed for single use and disposed after use to avoid contamination between patients.
	Cycling	N/A
	Intensifying	N/A

As presented in Table 6, Pilot 2.2 addresses sustainable manufacturing for electronics within the application field of medical electrode ECG under wearable health monitoring. The product lifetime is 12 months, with one time of use per electrode due to contamination prevention requirements. The circular approach focuses primarily on material substitution by replacing silver paste with carbon or copper paste and substituting PET plastics with paper or other sustainable substrate materials. The product remains single-use and is disposed after use; therefore, extending and intensifying strategies are limited in practical application. Value generation depends on collaboration among manufacturers, material suppliers, retailers, logistics companies, and waste collection points across the product life cycle stages from raw material extraction to disposal. Economic performance is linked to maintaining the same functionality and price level while enabling potential lower production costs and energy savings in manufacturing. Overall, the CBM represents a sustainable manufacturing transition within the health technology sector through improved material selection and end-of-life consideration.

4.1.6. Pilot 2.3: Sustainable dashboard for automotive

Table 7 provides an overview of the CBM design template developed for Pilot 2.3.

Table 7. CBM design template for Pilot 2.3.

Sustainable dashboard for automotive		
CBM Dimension	**Sub-category**	**Interpretation**
Value Proposition	**Products**	The product is designed with reduced material use, high durability, watertight construction, and simplified manufacturing processes, supporting circular design and improved quality-to-price performance.
	Services	Service activities are mainly handled by the OEM, while the Tier 1 supplier enables disassembly through product design to support the refurbishment of selected components.
Value Delivery	**Target customers and users**	The primary customers are automotive OEMs responding to EU end-of-life regulations requiring improved circular design, increased recycled content, and enhanced material recovery.
	Value delivery processes	Delivery is supported through sustainable materials, sustainable packaging, and logistics considerations that reduce waste and facilitate return, repair, and reuse.
Value Creation	**Key partners and stakeholders**	Value creation involves material suppliers, dashboard manufacturers, Tier 1 suppliers, OEMs, and recycling facilities collaborating to enable circular implementation.
	Value creation processes	Processes include thin applications with reduced material consumption, biomaterial substrates, and design for upgradability to support longer use and refurbishment.
Value Capture	**Revenues**	Value is captured through extended product lifetime, refurbished interiors enabling additional sales after production, and access to recycled high-value raw materials.
	Cost	Key cost drivers include disassembly and recycling processes, while long-term cost benefits arise from reintroducing production scrap and reducing dependency on virgin raw materials.
Circular economy design strategies	**Extending**	The product applies long-lasting design and timeless design principles to support extended use phases.
	Cycling and Intensifying	Cycling is planned through future recycling enabled by disassembly, while intensifying is supported by potential digital tracking via a Digital Product Passport (DPP).

As shown in Table 7, the CBM for Pilot 2.3 focuses on durable and lightweight product design supported by collaborative value creation across the automotive supply chain, with circularity primarily addressed through extending and cycling strategies. The pilot targets long-term use conditions, with a product lifetime of approximately 15 years, and is applied in the automotive application field, aligning product design, delivery processes, and value capture with EU End-of-Life regulatory requirements while enabling future recycling and refurbishment pathways.

4.1.7. Pilot 3.1a: In-Vitro Diagnostics (IVDs)

Table 8 shows the CBM design template for Pilot 3.1a, focusing on an environmentally compatible single-use diagnostic solution for home-based healthcare applications, and outlining how product, service, value delivery, value creation, and design strategy elements are addressed within the pilot scope.

Table 8. CBM design template for Pilot 3.1a.

In-Vitro Diagnostics (IVDs)		
CBM Dimension	**Sub-category**	**Interpretation**
Value proposition	**Products**	The pilot is based on a sustainable single-use sensor platform using paper substrate, sustainable LFD materials, copper ink printing, and biodegradable design.
	Services	The service element focuses on home-based diagnostics enabled using smartphones as reader devices.
Value delivery	**Target customers and users**	The primary users are high-risk patients performing diagnostic testing at home, supported by healthcare providers and laboratories.
	Value delivery processes	Delivery relies on minimal and sustainable packaging, careful material selection, and energy-efficient logistics to reduce environmental burden.
Value creation	**Key partners and stakeholders**	Value creation involves manufacturers, material suppliers, healthcare professionals, logistics providers, regulators, and public health stakeholders.
	Value creation processes	Core activities include sustainable product design, component and material selection, and enabling decentralized diagnostic testing at home.
Value capture	**Revenues**	Revenue is generated through the sale of single-use diagnostic products and subscription-based delivery for home users.
	Cost	Costs relate to manufacturing, sustainable packaging, energy-efficient distribution, and regulatory certification requirements.
Circular economy design strategies	**Extending and intensifying**	Extending is not applicable due to the single-use design, while intensifying is achieved through the design of home-based diagnostic services that replace laboratory-based testing.
	Cycling	Cycling is not considered applicable due to hygiene, contamination risk, and single-use clinical requirements of urine-based diagnostics.

The table synthesizes the CBM specified for a single-use In vitro diagnostics (IVDs) product within healthcare and diagnostic applications. The CBM combines a biodegradable sensor platform with service elements that support home-based testing through smartphone readers and subscription-based access. Value delivery and value creation are structured through material selection, packaging, logistics, and collaboration among healthcare and supply-chain actors, while value capture reflects product provision and service access. Circular economy considerations are addressed through product and system design choices, rather than post-use recovery, in accordance with the single-use design of the diagnostic application and related clinical requirements.

4.1.8. Pilot 3.1b: Smart Patch

Table 9 depicts the CBM design template for Pilot 3.1b (Smart Patch), summarizing how product and service elements, value delivery and value creation processes, and circular economy design strategies are configured within the pilot. The table highlights the alignment between health performance objectives and environmentally compatible design choices reflected in the CBM structure.

Table 9. CBM design template for Pilot 3.1b.

Smart Patch		
CBM dimension	**Sub-category**	**Interpretation**
Value proposition	**Products**	The pilot offers a durable hardware platform combined with a single-use Smart Sweat Patch designed to reduce waste compared to conventional disposable glucose monitoring alternatives through eco-design and material selection.
	Services	Digital services include app-based monitoring, AI-supported health suggestions, and optional leasing arrangements for use cases where non-invasive glucose monitoring is required.
Value delivery	**Target customers and users**	The primary users are diabetic patients (type 1 and type 2) and healthcare professionals, with the solution aiming to reduce hospital visits and associated healthcare emissions.
	Value delivery processes	Delivery is supported through sustainable material choices, local manufacturing, distributed production facilities, and pharmacy-based distribution and collection points.
Value creation	**Key partners and stakeholders**	Value creation involves collaboration with material and electronic component suppliers, logistics providers, healthcare professionals, sustainable technology actors, and policy stakeholders related to end-of-life management.
	Value creation processes	Processes focus on durable hardware design, integration of sustainable or recyclable materials based on LCA considerations, repair and refurbishment systems, and recycling partnerships for consumable components.
Value capture	**Revenues**	Revenue streams include hardware sales, recurring Smart Sweat Patch supply, app subscriptions and updates, and leasing of hardware for healthcare settings.
	Cost	Cost structures reflect manufacturing, distribution, collection, R&D, and regulatory certification, with long-term cost efficiency expected through material recovery and waste reduction.
Circular economy design strategies	**Extending**	Product support, customer education, and long-lasting hardware are used to extend the useful life of durable components within the system.
	Cycling	Repair, refurbishment, and recycling activities are applied to durable hardware and selected components, while respecting single-use constraints of the consumable patch.
	Intensifying	System intensification is achieved through digital monitoring, app upgrades, and service-based delivery that reduce the need for additional devices and in-person healthcare visits.

Pilot 3.1b is characterized by a product lifetime associated with daily, weekly, or monthly use patterns, a single use per Smart Sweat Patch, and an application field covering healthcare, diagnostics, and wearable technologies. These characteristics indicate that the circular approach adopted in the pilot does not rely on reuse of the consumable patch. Instead, circularity is addressed through durable hardware design, controlled service-based delivery, and digital system intensification, which together reduce material demand, limit healthcare visits, and lower associated emissions. The resulting CBM represents an environmentally

compatible single-use electronics configuration that remains consistent with clinical and hygiene requirements in diabetes monitoring and care.

4.1.9. Pilot 3.2: Smart hygiene

The CBM design template for Pilot 3.2 (Smart hygiene) outlines how the CBM value dimensions are configured within the pilot, as seen in Table 10.

Table 10. CBM design template for Pilot 3.2.

Smart hygiene		
CBM dimension	**Sub-category**	**Interpretation**
Value proposition	**Products**	The product offering combines reusable components such as a transmitter or reader (designed for reuse and extended use) with a single-use sensor label designed for environmentally compatible use in hygiene and healthcare applications.
	Services	Service elements include repair, maintenance, reuse, and technology upgrades, supported by data analysis to enhance monitoring and personalized care insights.
Value delivery	**Target customers and users**	The main users are hospitals, nursing homes, and medical personnel, including care givers for home use.
	Value delivery processes	Value is delivered through access to product functionality, sustainable and minimal packaging, reduced emissions via material choices, and integration with existing diaper delivery and hygiene product handling channels.
Value creation	**Key partners and stakeholders**	Value creation involves collaboration among manufacturers, senior care homes, suppliers, and logistics, retail, and waste collection partners.
	Value creation processes	Value creation focuses on designing products, components, and materials to enable circular use, organizing take-back and recapturing flows for products and materials where feasible, supporting continuous health monitoring to improve care efficiency, and establishing a closed-loop supply chain.
Value capture	**Revenues**	Revenue generation is based on PaaS leasing, and subscription arrangements rather than ownership-based sales.
	Cost	Cost structures include manufacturing, energy-efficient delivery, and initial investments required to establish a closed-loop supply chain oriented toward remanufacturing.
Circular economy design strategies	**Extending and cycling**	Extending and cycling strategies apply to the durable electronic components, such as the transmitter or reader and the associated smartphone interface, through repair, refurbishment, reuse, recycling, modular design, and upgradability that support prolonged functional use of the hardware.
	Intensifying	Intensifying strategies focus on shared and repeated use of the reusable transmitter or reader, supported by associated digital services accessed via smartphones. These strategies are implemented through rental and PaaS arrangements, enabled by digital monitoring, service coordination, and usage-based pricing. The single-use sensor label is excluded from intensification due to hygiene requirements.

As shown in Table 10, Pilot 3.2 applies a hybrid product structure that combines a reusable transmitter or reader designed for extended use with a single-use sensor label intended for recycling within healthcare applications. The product lifetime is limited to Approx. 8 hr for a single user, with the durable component designed for multiple reuse cycles and the sensor label intended for one-time use. The CBM emphasizes service-based access, repairable electronics, closed-loop material management, and digitally supported service intensification, while remaining aligned with hygiene, clinical, and operational requirements in healthcare.

4.1.10. Pilot 3.3: Smart wound dressing

Table 11 summarizes the CBM design template applied in Pilot 3.3, Smart wound dressing.

Table 11. CBM design template for Pilot (3.3).

Smart wound dressing		
CBM dimension	**Sub-category**	**Interpretation**
Value proposition	**Products**	The pilot offers a smart wound dressing that enables early infection detection, continuous wound monitoring, and reduced disturbance of wound healing through reusable electronic components combined with single-use parts.
	Services	The pilot supports a healthcare service focused on therapy improvement, data-enabled tracking of wound status, and reduced workload for healthcare professionals in home care and hospital settings.
Value delivery	**Target customers and users**	The solution targets patients with chronic wounds, healthcare professionals, and informal caregivers, with application in both home care and hospital environments.
	Value delivery processes	Digitalized data access enables distributed clinical decision-making across locations while supporting continuous monitoring and personalized wound care.
Value creation	**Key partners and stakeholders**	Value is created through collaboration among dressing material manufacturers, electronics suppliers, data platform providers, healthcare professionals, and health insurance companies.
	Value creation processes	The system is designed for modularity, patient-specific reuse, sterilizable electronics, and regulated disposal of wound-contact parts through hospital waste management.
Value capture	**Revenues**	The CBM explores PaaS and potential leasing arrangements for reusable components, subject to sterilization and data security feasibility.
	Cost	Cost efficiency is pursued through investment in robust reusable electronics, reduced healthcare workload, and improved healing outcomes, despite challenges related to reuse-induced revenue shifts for component suppliers.
Circular economy design strategies	**Extending**	The pilot applies long-lasting and rechargeable electronic components, modular design, upgradability, and maintenance-oriented product support.
	Cycling and intensifying	Circularity is supported through reuse, repair, refurbishing, recycling of electronics, and service-based access models enabled by digital monitoring and contract-based care delivery.

Pilot 3.3 addresses chronic wound care by combining single-use dressing materials in wound contact with reusable and rechargeable electronic components, including the flex PCB, read-out unit, and rechargeable battery. All wound-contact parts are single use and disposed of through incineration in accordance with regulations, while reuse applies only to electronic components outside the wound area and is dependent on sterilization and disinfection. The CBM emphasizes continuous wound monitoring and digitalization of information across healthcare settings, remaining consistent with hygiene, clinical, and data privacy requirements in the healthcare sector.

4.2. Circular Business Model Archetypes

This section develops general CBM archetypes based on systematic comparison of the health technology pilots. Building on the pilot-level "CBM design templates", recurring circular configurations are synthesized at product-category level. The archetypes consolidate shared approaches to product architecture, service structures, stakeholder roles, and circular economy design strategies across the defined categories.

The following subsections introduce the archetypes for each product category.

4.2.1. Product category definition and pilot scope

The development of general CBM archetypes was based on eight pilot projects grouped into three product categories (PCs). The categorization reflects shared product architecture, usage context, and circular design constraints (Table 12. Product categories and corresponding pilot project titles for CBM archetype development). This categorization enabled systematic cross-case comparison and supported the identification of general CBM archetypes across the health technology sector.

Table 12. Product categories and corresponding pilot project titles for CBM archetype development

Item	PC	Pilot project
1	Durable systems and devices	• Pilot 1.1: Image-guided therapy systems (IGTS) • Pilot 1.2: Personal grooming devices
2	Wearable medical/health devices	• Pilot 2.1: Embedded electronics for monitoring • Pilot 2.2: Wearable health monitoring • Pilot 3.1b: Smart patch • Pilot 3.2: Hygiene products • Pilot 3.3: Wound dressings
3	Diagnostic medical device	• Pilot 3.1a: Diagnostics tool

- **PC-1: Durable systems and devices:**

This category comprises complex electronic systems and consumer devices characterized by repeated use, modular electronic components, and defined return or service pathways.

- **PC-2: Wearable medical/health devices:**

This category comprises body-worn devices that integrate electronic components with hygiene-sensitive, disposable, or replaceable elements. It includes embedded electronics for monitoring (Pilot 2.1), wearable health monitoring devices (Pilot 2.2), smart patches (Pilot 3.1b), smart hygiene products (Pilot 3.2), and wound dressings (Pilot 3.3).

- **PC-3: Diagnostic medical devices**

This category includes diagnostic solutions that combine reusable electronic parts with single-use or consumable components, represented by the diagnostics tool pilot (Pilot 3.1a).

Two pilots (Pilot 1.3: Sustainable luminaire and Pilot 2.3: Sustainable dashboard for automotive) were not included in the development of the general CBM archetypes, as their application contexts and circularity requirements differ from those of the health technology pilots.

4.2.2. PC-1: General CBM archetypes for durable systems and devices

The general CBM archetypes for PC-1 include 1) Prolonging product life and 2) Return and material circularity. These archetypes address circularity in durable health-technology systems through extending and cycling circular economy strategies, while respecting safety, hygiene, and quality requirements in healthcare applications.

CBM value dimensions

- **Value proposition:** Product design supports repair, upgrade, refurbishment, and part replacement through modular and repairable system architectures. Circular value is created through selective reuse of recovered components and secondary materials. Components with Dermal or skin contact are excluded from reuse and directed to material recovery to ensure user safety and hygiene compliance.
- **Value delivery:** Certified take-back programs and traceable reverse logistics enable safe and reliable return of used devices, components, and materials. Low-emission logistics and return procedures support controlled handling throughout the product lifecycle.
- **Value creation:** Component recovery, refurbishment, and recycling processes improve resource efficiency and support quality-controlled operations. Collaboration with suppliers and local refurbishment partners enables safe processing of note devices while contributing to skilled employment and safe working conditions.
- **Value capture:** Economic value is generated through revenues from refurbished parts and systems, reduced maintenance and material costs, and longer time between replacements. For large medical systems, buy-back of branded equipment supports quality assurance and controlled reuse within healthcare settings.

Sustainability benefit dimensions

- **Environmental:** Reduced material use, lower emissions, and closed material loops are achieved through repair, refurbishment, selective reuse, and material recycling.
- **Economic:** Cost savings are realized through extended product lifetimes, lower procurement needs, reduced maintenance costs, and improved resource efficiency for manufacturers and healthcare providers.
- **Social:** Transparent return logistics, trusted repair services, and refurbishment activities support social responsibility. User and patient safety are ensured through the separation of hygiene-critical and dermal-contact components from reuse (Grooming beauty device).

4.2.3. PC-2: General CBM archetypes for wearable medical/health devices

The general CBM archetypes for PC-2 include Device as a service platform. This archetype addresses circularity in wearable medical and health devices by integrating cycling and intensifying circular economy strategies through service-based and digitally enabled solutions, while operating under strict safety, hygiene, traceability, and reliability requirements in healthcare applications.

CBM value dimensions

- **Value proposition:** Reusable and repairable electronics, combined with separation between reusable and single-use components, reduce material waste and support multiple use cycles while maintaining medical safety and hygiene standards.
- **Value delivery:** Remote and software-based services lower transport-related emissions and maintenance needs, while enabling continuous monitoring, diagnostics, and lifecycle traceability through digital product passports.
- **Value creation:** Collaboration between manufacturers, healthcare providers, and recyclers ensures safe reuse, reliable device performance, and certified recovery processes across the product lifecycle.
- **Value capture:** Revenues are generated through subscription-based and leasing models, as well as data-driven monitoring services, supporting extended product use, improved recovery efficiency, and optimized lifecycle costs.

Sustainability benefit dimensions

- **Environmental:** Reduced material uses and lower emissions are achieved through selective reuse of durable electronics, certified refurbishment, separation of single-use components, and material recovery supported by traceable reverse flows.
- **Economic:** Cost efficiency is supported through extended use of wearable devices, subscription and leasing-based access models, reduced maintenance and logistics needs, and improved recovery efficiency for manufacturers and healthcare providers.
- **Social:** Patient and user safety are supported through controlled take-back processes and certified recovery systems, while hygiene-critical and dermal-contact components are not reused. Moreover, digital monitoring and traceability enhance transparency and build trust across healthcare settings.

Circular economy design strategies

- **Cycling** is achieved through the reuse of durable electronic components, such as readers and transmitters, enabled by certified take-back systems, second-hand channels, and traceability supported by DPPs. Safe separation and certified recovery of single-use components ensure hygiene and regulatory compliance.
- **Intensifying** is implemented through real-time monitoring, remote diagnostics, and software-based services that increase device utilization, reduce in-person visits, and extend effective use across multiple users and settings.

This archetype reflects the increasing importance of digital integration, hygiene management, and lifecycle traceability in wearable healthcare technologies. Evidence from smart patches, wearable health monitoring systems, smart hygiene solutions, and wound-dressing devices shows that the device as a service platform enables continuous data-driven care across hospitals, home settings, healthcare professionals, and patients. The approach improves patient safety, supports remote healthcare delivery, reduces maintenance needs, and enables certified refurbishment and recovery, contributing to environmental, social, and economic sustainability in the wearable healthcare industry.

4.2.4. PC-3: General CBM archetypes for diagnostic medical devices

The general CBM archetypes for PC-3 include Sustainable materials and energy-efficient digital access (service/logistics). This archetype addresses circularity in diagnostic medical devices, particularly single-use sampling tests combined with reusable readers, by integrating cycling, extending, and intensifying circular economy strategies. The archetype operates under strict end-of-life management, safety, and regulatory requirements that characterize diagnostic applications in the health-technology sector.

CBM value dimensions

- **Value delivery:** Digital access and connectivity enable home-based testing, remote diagnostics, and continuous monitoring, while localized warehousing and digitally supported logistics reduce delivery distances, energy use, and response times.
- **Value creation:** Collaboration among device manufacturers, material suppliers, recyclers, logistics providers, and digital platform partners supports biodegradable design, certified end-of-life recovery, safe disposal, and closed-loop material flows.
- **Value capture:** Economic value is generated through subscription-based access to diagnostic services and digital monitoring solutions, alongside cost savings from reduced logistics requirements, lower packaging needs, and decreased energy use across distribution and service delivery.

Sustainability benefit dimensions

- **Environmental:** Reduced waste and lower environmental impacts are achieved through biodegradable disposable components, reuse of smartphone readers, certified end-of-life recovery, and energy-efficient logistics enabled by digital access and local distribution.
- **Economic:** Cost efficiency is supported through subscription-based service models, reduced manufacturing demand for electronic readers, lower distribution and logistics costs, and savings associated with energy-efficient and digitally coordinated service delivery.
- **Social:** Diagnostic accessibility is improved through home-based testing and decentralized healthcare solutions, particularly for remote users, while patient and staff safety is supported using biodegradable materials and certified disposal and recovery processes.

Circular economy design strategies

- **Extending** is achieved through reuse of smartphone readers as diagnostic interfaces, reducing demand for new electronic devices while maintaining diagnostic functionality and safety.
- **Cycling** is implemented through the incorporation of biodegradable components in disposable tests and compliance with certified end-of-life recovery requirements, ensuring safe disposal and material recovery.
- **Intensifying** is enabled by digital monitoring, energy-efficient logistics, and localized warehousing, which increase service efficiency, reduce emissions, and optimize resource use across diagnostic service delivery.

This archetype demonstrates an integrated CBM approach for diagnostic medical devices, where material design, digital service delivery, and logistics are jointly optimized. Evidence from diagnostic systems combining biodegradable sampling components with reusable digital readers shows how circular strategies can be applied in practice while balancing patient safety, cost efficiency, and energy performance. By linking sustainable materials with energy-efficient digital access, this archetype illustrates a practical pathway for circular transformation in diagnostic healthcare technologies.

5. Review of Circular Business Models

5.1. Methodology

CBMs focus on products and services with the aim to advance companies' transition towards the circular economy which requires measuring the process with performance indicators both on the product and service levels (Kühl et al., 2023). Circular economy-related key performance indicators (KPIs) are still very company-specific and there is a lack of KPIs for benchmarking the activities at an industry-level for extensive product service systems that are set up in the health technology, lighting and automotive sectors.

In the circular economy, economic growth is decoupled from the consumption of resources and for tracking the transition to circular economy, companies need to measure and monitor their progress both on the product and service levels to understand if they are using resources as required and achieving their sustainability targets (Kjaer et al., 2019). Among the most frequently used KPI for tracking transition to the circular economy is the 'recycling rate' which is used to monitor waste management efficiency. However, as quantity-based metric it cannot capture the complex early-stage product development activities and required more systemic changes on the circular economy ecosystem level (Yang et al., 2023).

Recent literature has focused more on the supply chain perspective when developing performance indicators, for example in the health care sector (Alfina et al., 2025). However, these KPIs require data that is only available when the products and services have been deployed and scaled on the markets. Thus, these are more applicable when product and service development projects are moving from the product development phase to the product scaling in the commercialization phase.

In the early product development phase, the KPIs that are applied in the Sustronics project are derived from the eco-design principles and LCA measurements conducted in the beginning of the project. These have been applied in the CBM Design Template for each of the pilots. The KPIs from the early product development phase have been collected and reported in the CBM templates (see Sections from 4.1.1.-4.1.10). These KPIs have then been used to assess the validity of the product and service development for the CBM designs.

Additional KPIs are suggested for the later stages in the product development process, when the pilot projects are launching their products on the markets, starting from TRL 8 focusing on system testing and further in the TRL 9 stage that focuses on wider commercial deployment. In the TRL 7 phase that still focuses on the prototype, the selection and initial target value setting for the selected KPIs should be agreed within the companies and among stakeholders, also in the supply chain. The target values for the KPIs should then be included in the company level business strategy as the sustainability KPIs. These are figures that will also be reported then in the ESG reporting of the companies.

First, below there is a list of the early product development phase KPIs derived from the eco-design principles and LCA measurements that were applied in the Sustronics project.

KPI Framework for Assessing CBM Viability and Sustainability

The assessment of CBM viability and sustainability requires a structured yet adaptable performance framework. In the Sustronics project the KPIs are developed to evaluate the economic, environmental, operational, and social dimensions of circular configurations across the ten pilot cases.

General KPIs applicable to the product development phase

<u>Products:</u> Degree of use of design and circular design principles in the product design, focusing on the extent to which it is applied in different areas of the product design and how it supports the circular economy targets:

1. sustainable materials in the product (e.g. bio-based materials)
2. reduction of use of materials due to the reduction of the size of the product
3. reduction of packaging materials
4. durability of product (longer product lifetime than for similar other products)
5. modularity of the product
6. repairability with replacement of critical parts
7. recyclability of materials
8. reduction of number of components
9. reduction of the size of components
10. reusable components combined with single-use parts
11. simplified production processes
12. reduction of product use related waste

<u>Services:</u> designed to complement the product with the target to further implement the eco-design and circular design principles that focus on extending, cycling and intensifying the use of the physical products:

1. product take back schemes enabling reuse of components by recovery
2. repair services planned already in the product design phase
3. replacement of critical components
4. upgrades with modular tools
5. faster installation services for complex products
6. refurbishment services
7. recycling services
8. services to B2B customers to assist in the replacement of non-sustainable materials with more sustainable materials
9. easy disassembly as service for refurbishment for refurbishment purposes
10. digital services enabled with mobile phone applications – requiring less travelling of users of products
11. leasing of products – thus offering, for example, *monitoring of health or light as a service*
12. maintenance services supported by data analytics
13. reuse services supported by data analytics
14. technology upgrades services supported by data analytics
15. remote tracking of state of health (wound healing, health measurement results, etc.)

<u>Value delivery processes</u>: Value added in the delivery of the product and service.

1. logistics
2. packaging, e.g. reusable packaging
3. space needed for use of product
4. reuse potential
5. reduction of plastic
6. reverse supply chain for collection and recycling
7. adjustability
8. reusable packaging
9. structured management of refurbishments
10. product design integrating sustainably electronics into mechanical parts
11. reduction of waste
12. facilitated returns, repairs and reuse

13. energy-efficiency considerations in, e.g. use phase and logistics
14. local manufacturing
15. collaboration with stakeholders in distribution and take back schemes
16. distributed clinical decision making with extended patient care capability in home care facilities

Value creation processes: Value added with the creation of the product and service.

1. modularity extending product lifetime and upgradability
2. reduction of carbon footprint with smaller product sizes reducing manufacturing and logistics emissions
3. closed-loop supply chains considered
4. material reuse processes designed to reduce waste
5. shortening time needed for patient recovery and hospital stays
6. component reuse
7. refurbishment and remanufacturing
8. decentralized patient care in home facilities
9. improving patient care efficiency
10. patient-specific reuse,
11. sterilizable electronics

Revenues: Revenue-level value captured by the product and service.

1. servicing contracts
2. subscription or pay-per-use arrangements
3. reuse of components
4. customer retention with service-based contracts
5. product-as-as service offerings
6. sales of refurbished products
7. access to recycled high-value raw materials
8. mobile phone app subscriptions and updates for services supporting products
9. leasing of hardware for health care settings

Costs of the value captured by the product and service:

1. lower costs of materials, packaging and installations
2. longer lifetime reduces product replacement costs
3. cost efficiency supported by reverse logistics
4. less material costs due to reduced need for materials, as a result of reuse and recycling
5. energy efficiency in manufacturing and delivery results in energy cost savings
6. reduced material waste management
7. regulatory certification costs
8. cost efficiency through material recovery and waste reduction
9. initial investments required to develop a closed-loop supply chain for remanufacturing
10. Cost efficiency through investment in robust reusable electronics, reduced healthcare workload

General KPIs applicable to the product launch phase (TRL 9)

The KPIs are organised under 3 overarching performance dimensions (based on Alfina et al., 2025): economic viability, environmental sustainability, and social and safety performance.

Economic viability

Assesses whether the circular configuration is financially feasible and scalable. Key aspects include:

- Revenue from refurbishment or service-based offerings
- Cost savings from component reuse
- Asset utilization efficiency

Environmental sustainability

Assesses circular material flows and environmental impact reduction. Key aspects include:

- Material recovery rate
- Reuse rate of components
- Reduction in virgin material consumption
- LCA-based impact comparison (where data is available)

Social and safety performance

Relevant in the health technology sector. Key aspects include:

- Patient / User safety
- Hygiene
- Accessibility of home-based or remote services
- Service continuity

Since these aspects are targeting the phase after product launch, which is still far from the current state of the pilots, these KPIs are not evaluated in this deliverable, as is further explained in Section 5.3.

5.2. Results

The circular business model related KPIs can be assessed by tracking how many of the pilot use cases have applied the different principles described in the CBM template. As the pilot cases are all unique and also focus on developing different aspects in their sustainable circular designs, the pilot case ***circular design KPIs*** present a broad scope of different aspects. This can be seen in the bar charts below presenting in how many pilots the different General KPIs applicable to the product development phase (Listed under Section 5.1) have been achieved.

Circular product design KPI

For the circular product design, the main achievements are in the way they have managed to use sustainable materials in the product, and also the reduction of packaging materials and the durability of the product have been achieved in the product development.

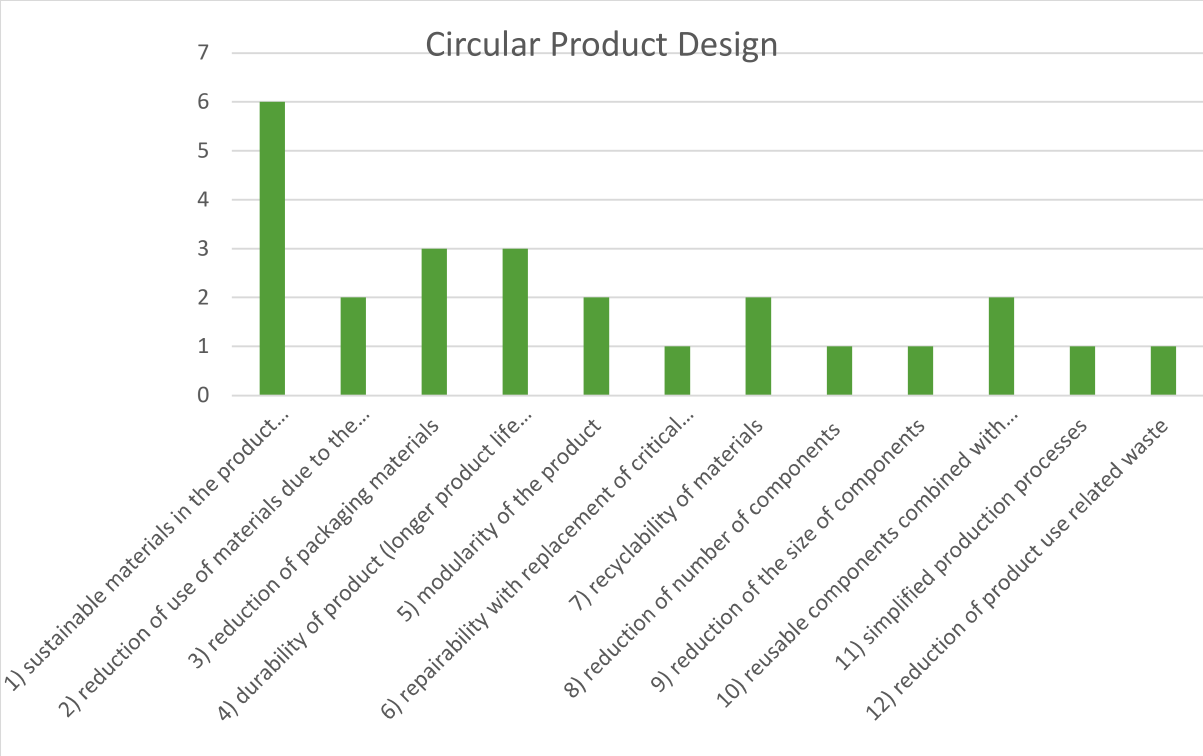


Figure 3: Number of pilots that applied circular product design KPIs.

Circular service design KPI

In the circular service design, the refurbishment services is one of the areas where multiple pilots have been able to reach some results. In addition, digital services via apps and remote tracking, as well as repair services and replacement of critical components were something that was achieved by several pilots.

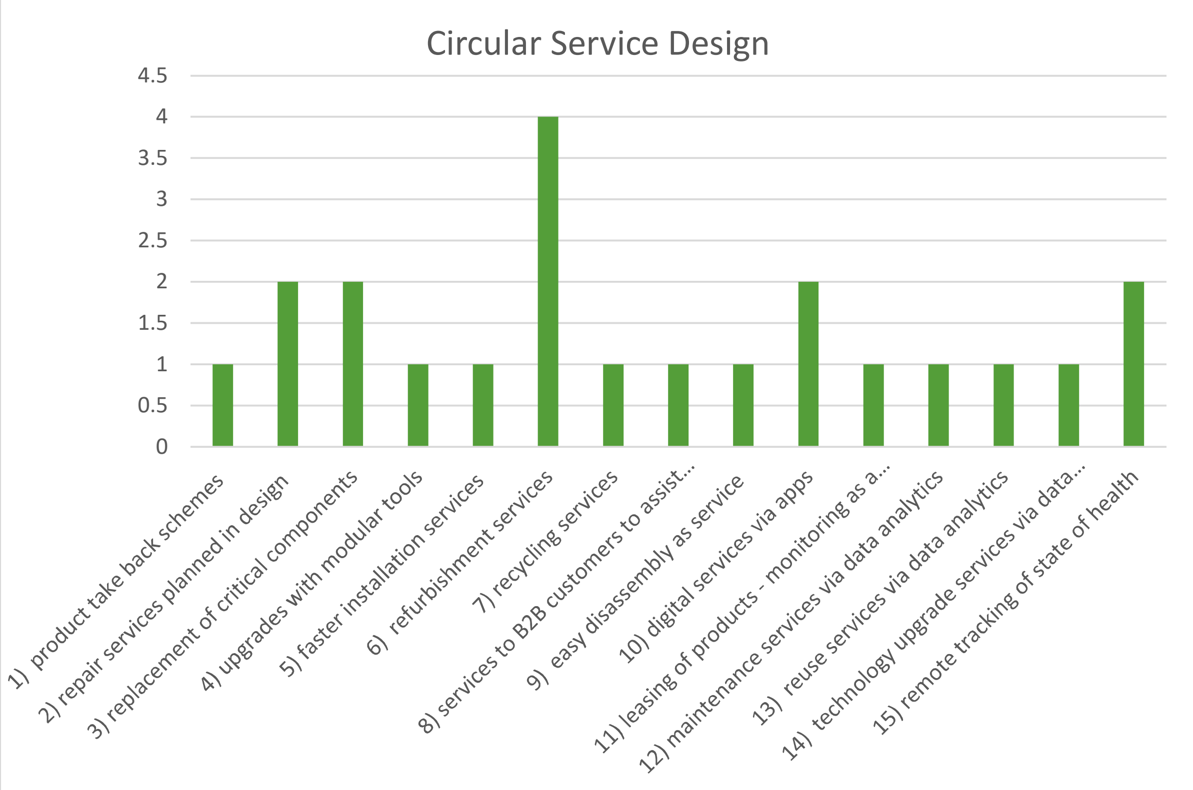


Figure 4: Number of pilots that applied circular service design KPIs.

Value added in the delivery of the product and service

For sustainable value added in the delivery of the products and services, the packaging offered the most opportunities to reduce waste and create savings. The logistics was also seen by some pilots as a potential area where some sustainable value can be created by reconsidering it and reducing the need for travelling, for example, by patients to health care or hospitals.

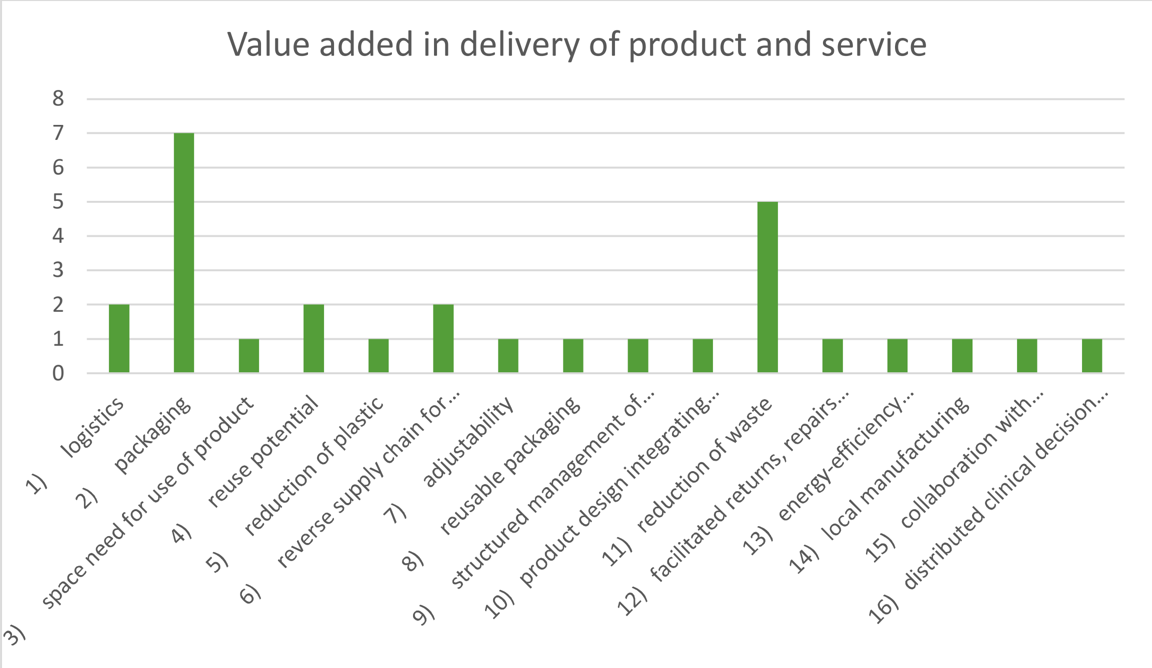


Figure 5: Number of pilots that applied sustainability KPIs on value added in delivery of products and services.

Value added with the creation of the product and service

In the actual creation of the product and services, multiple pilots identified the potential for designing material reuse processes to reduce waste, as well as considered component reuse, refurbishment and remanufacturing. In several pilots also closed loop supply chains were considered. Some pilots also found ways for extending product lifetime and upgradability with modular design. There were also patient-specific reuse cases identified in some pilots.

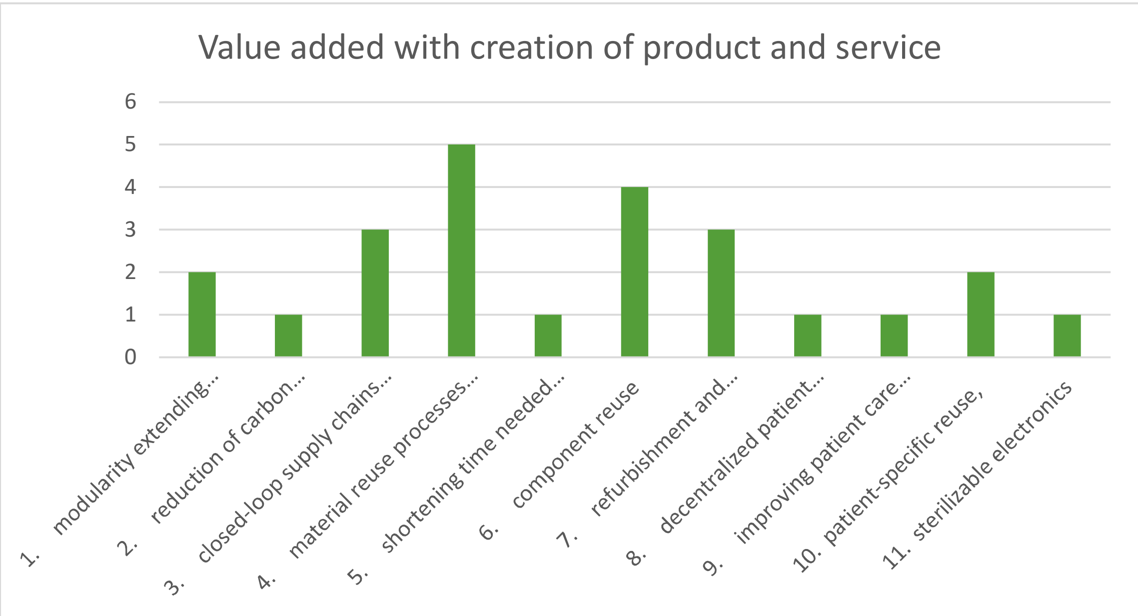


Figure 6: Number of pilots that applied sustainability KPIs on value added with the creation of products and services.

5.3. Discussion

In projects where the targeted technology readiness level (TRL) is still fairly low and the objective is not to finalize the product and services for the real-world, it is not realistic or even feasible to use KPIs meant for fully commercialized products and services.

The objectives for circular innovation beyond the state-of-the-art in the original Sustronics plan were described on TRL levels. The ones that are applicable to product level development include: ***Bio-based substrate materials***, ***Abundant conductive materials***, ***Component assembly***, ***Sustainable manufacturing***, ***Components with ecodesign and circular design***. Additional objectives are linked to service development, these include: ***Sustainable software functionalities for energy efficiency***, ***End-of-life management***. We have focused on validating what kind of circular product and service development has been conducted and in how many of the pilot cases specific circular and ecodesign principles and targets have been applied. The KPIs can also be mapped across the TRLs, and in the case of Sustronics the target TRLs were spread from ***TRL 2/3 to TRL 5/6***. The chart below shows how the collaboration is divided between universities/research institutes and the industry.

Universities			Collaboration b/n universities & industry				Industry	
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Observing basic principles	Concept developed and testing	Proof of concept	Tech. validation in lab	Tech. validation in relevant environment	Tech. demo in operation	System demo in real world	System complete and qualified	Actual proof of real-world system operation

Figure 7: Mapping of TRLs on universities and industry.

(EURAXESS, n.d.; Hensen, 2015).

Table 13 and Figure 8 summarize how much the pilots were able to achieve in the circular product and service design indicated by the number of circular design KPI areas where they reached the objectives of ecodesign principles, and which have been the main circular design KPIs. However, in addition, other ecodesign principles have also been considered as much as possible.

Table 13. Circular design KPIs covered by each pilot.

Sustronics pilots	Number of circular design KPIs applied
Pilot (1.1): Green and circular image guided therapy systems (IGTS)	19
Pilot (1.2): Sustainable system integration & product design of personal health devices	14
Pilot (1.3): Sustainable luminaire	16
Pilot (2.1): Embedded electronics for EEG monitoring	10
Pilot (2.2): Wearable health monitoring	7
Pilot (2.3): Sustainable dashboard for automotive	11
Pilot (3.1a): In-Vitro Diagnostics (IVDs)	8
Pilot (3.1b): Smart Patch	11
Pilot (3.2): Smart hygiene	14
Pilot (3.3): Smart wound dressing	8

Figure 8 illustrates the number of circular design KPI areas applied in each pilot. The figure shows that the pilots differed in the number of circular design areas covered, reflecting their different product types, technology readiness levels, hygiene requirements, and reuse possibilities.

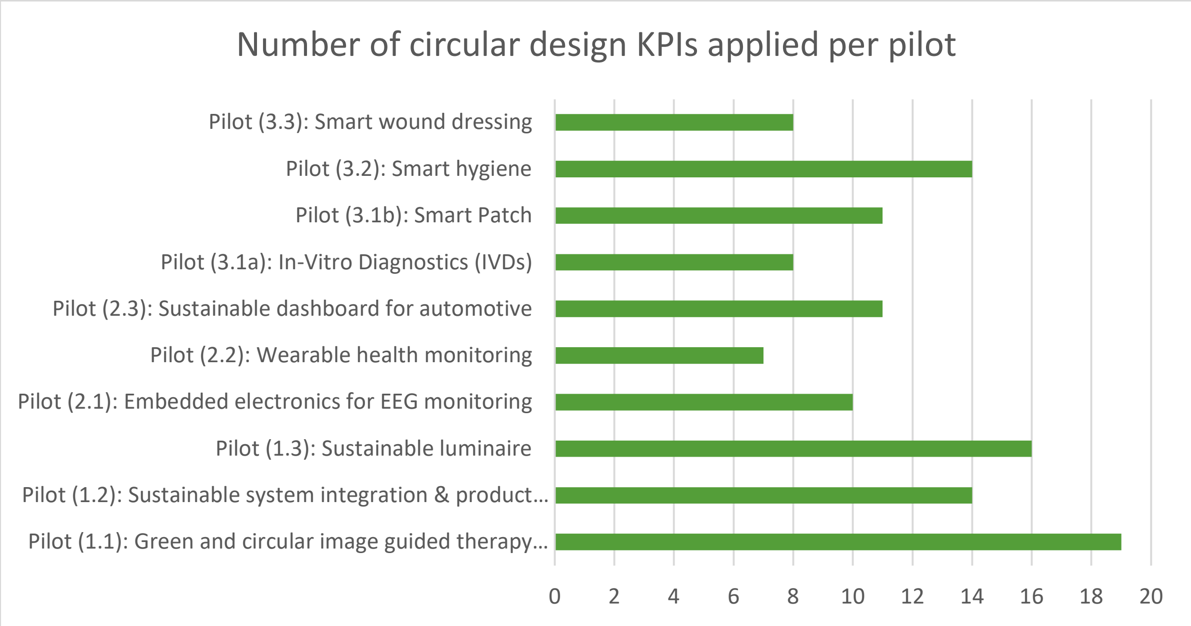


Figure 8. Circular design coverage per pilot.

Durable systems and devices covered a wider set of circular design indicators because they offered stronger possibilities for repair, refurbishment, service contracts, and material recovery. Single-use or hygiene-sensitive applications covered fewer indicators but still contributed through sustainable materials, reduced packaging, digital services, and safe end-of-life considerations.

The assessment indicates that CBM design was reflected in product features, service elements, delivery processes, and value creation activities across the pilots. The results also show that evaluation at early technology readiness levels should focus on the integration of circular and eco-design principles into product and service configurations, rather than on market-level circular performance.

6. Conclusion

Circular business models (CBMs) were developed for each pilot, and archetype CBMs were developed for three product categories. A review of the CBMs against KPIs that are well known from literature shows that a wide range of circular business strategies are covered both in design and service delivery across the pilots. Each of the pilots covers at least 7 of the KPIs showing great potential to eventually bring sustainability into their business models after launching the products. At the same time, the low TRL at which the pilots reside comes with great uncertainty about the viability of the business models and how they eventually will be applied.

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