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Project acronym: FRONTSH1P

Project title: A FRONTrunner approach to Systemic circular, Holistic & Inclusive solutions for a new Paradigm of territorial circular economy

Type of action: Deployment of systemic solutions with the support of local clusters and the development of regional community-based innovation schemes

Deliverable Number: D5.5

Ecodesign case studies CSS3

Framework for the Ecodesign activities

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Partners

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HISTORY OF CHANGES			
Version	Date	Author/Contributor	Changes
1	16.10.2023	LNEG	Draft version sent to CSS leaders
2	19.10.2023	NTUA	Suggestions and comments (all CSS)
3	07.11.2023	LNEG	CSS Leader review

Disclaimer

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Contents

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1. Executive Summary

The aim of the Ecodesign approach within the FRONTSH1P project is to identify measures that have the strongest leverage for an environmentally oriented improvement of a product or value chain, which will:

- Provide guidelines for LCA and S-LCA, integrating a circular design perspective and needs,
- Allow the identification of the circular design strategies, based on a tool developed in a previous project on circular design (the KATCH_e CE Designer tool- www.katche.eu) with more potential for the identified products,
- Lead to the identification of improvement opportunities and measures for the strategies – illustrated with examples and case studies.

Additionally, the Ecodesign activity within FRONTSH1P includes structuring the information, data, methodologies, and guidelines to support the development of the tool within WP7.

In view of this, the content of the present document is in accordance with the description of the activity in the Grant Agreement and goes beyond the designation of the respective deliverable.

The methodology used to implement Ecodesign in FRONTSH1P relies on the analysis of value chains involved in the CSS's, the mapping of environmental, social and economic value losses and the identification of opportunities to capture/recover that value, through the application of Ecodesign strategies and criteria. Five steps are undertaken, using specific templates that were created for each CSS using the 'Mural' collaborative platform:

- step 1 - the identification of all actors in the CSS's value chain,
- step 2 - the identification of the interactions between them,
- step 3 - the identification of value losses (environmental, economic and social),
- step 4 - the identification of Ecodesign opportunities based on the losses from step 3,
- step 5 - development of guidelines for improvement of the product, service, process and business model.

The resources developed to support the methodology are also presented in this document:

- Indicators and data needs,
- Checklists for value losses and opportunities identification,
- Circular design strategies and criteria,
- Examples and case studies.

The method is applied and tested to the CSS that is under LNEG's responsibility (CSS3), given that the Ecodesign team had easier access to more in-depth data and information from coworkers; this activity will be replicated in the other CSS's.

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2. Scope and Structure of the Deliverable

This deliverable will cover the following aspects of the Ecodesign and Design for Circularity activities under development within the FRONTSH1P project :

- The FRONTSH1P approach to Ecodesign and circular economy,
- An introduction to Ecodesign and circular economy within the FRONTSH1P context,
- A brief introduction of the aims and reference work carried out in the respective CSS,
- The methodology and framework developed to improve the Ecodesign and design for circularity in the project,
- A brief introduction to the resources developed to support the methodology:
  - Indicators and data needs,
  - Circular design strategies and criteria to implement in the CSS's to identify value losses and the identification and creation of opportunities, new solutions of products, processes, and business models,;
  - Checklists for value identification focusing on the value loss and opportunities,
- Examples and case studies to be used as inspiration and benchmarking,
- Ecodesign and Circular economy in FRONTSH1P CSSs. Practical application of the method with CSS3 as an example,
- Definition of guidelines to support the implementation on practice,
- Further developments.

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3. About FRONTSH1P

A FRONTrunner approach to Systemic circular, Holistic & Inclusive solutions for a new Paradigm of territorial circular economy (FRONTSH1P) is a European circular economy project that started on November 1st, 2021. It is funded by the European Union under the Horizon 2020 programme.

The project is centred in the Polish region of Łódzkie. A region that, on the one hand, traditionally heavily relies on coal extraction, and on the other hand, has pioneered circular (bio)economy since the early 2000s. The region has always been in the forefront of innovation and has become one of the leading regions in the field of circular economy. In the next 4 years, FRONTSH1P will contribute to further the green and just transition of the Łódzkie region away from its current linear economic foundation, towards the region's decarbonisation and territorial regeneration. It will do so by demonstrating four Circular Systemic Solutions. Each circular systemic solution targets an economic sector that is aiming towards decarbonisation: Wood Packaging, Food & Feed, Water & Nutrients, and Plastic & Rubber Waste. Each developed circular systemic solution will furthermore be highly replicable. A feat that will be proven during the project by their implementation in four other European regions: Campania (Italy), Sterea Ellada (Greece), Norte (Portugal), and Friesland (the Netherlands). Through the development of the circular systemic solutions, FRONTSH1P will create Circular Regional Clusters that involve a wide range of local, regional, and national stakeholders, both from the public and private spheres, guaranteeing that no one will be left behind. CSS3 is directed to solve specific problems as environmental services (decarbonization and wastewater treatment) together with the production of biobased products and bioenergy creating jobs and other benefits to either the community or neighbouring circular regions as well.

The development of the microalgae value chain is expected to bring circular solutions and resilience to the Łódzkie region (bio)economy, increasing self-sufficiency of bio-based products and limiting the need for imports.

Within the EU Algae Initiative by the EC, the Commission intends to boost the potential of the EU algae sector, supporting the development of upscaled regenerative microalgae cultivation and production, creating jobs for local communities, producing sustainable low-carbon products, regenerating ecosystems (e.g. fixing CO_2 from flue gases, nutrients from wastewaters and releasing oxygen), and providing environmental services. Most importantly the EU algae sector could become the success story that embodies the ambition of the European Green Deal to reinvent the EU economy with more sustainable, climate friendly and resilient industries and regions, fitting several FRONTSH1P CSS3 objectives.

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4. Introduction

The current production and consumption patterns are exceeding the Earth's carrying capacity and they can have severe consequences for our living conditions now and in the future. The overexploitation of resources, to meet the current needs, is linked to a linear economy or the take-make-waste paradigm based on the assumption that natural resources are available, abundant, easy to source and cheap to dispose of. The global economy is now only 7.2% circular, and it is getting worse by the year driven by rising material extraction and use (Circularity GAP report 2023). Therefore, we have to deal with global sustainability challenges, and we need a new circular approach to production and consumption systems (Schmidt et al., 2020).

This transition must be an integrated and holistic approach within which the all value chain contributes. The entire production and consumption system needs to change and be improved in innovative and sustainable ways. In this regard, the design practice makes an important contribution and has a key role in the definition of the features and the profile of products and services towards more sustainable solutions, focusing on "Use less, use longer, use again and make clean".

5. The FRONTSH1P approach to Ecodesign and circular economy

The aim of the Ecodesign approach within the FRONTSH1P project is to identify measures that have the strongest leverage for an environmentally oriented improvement of a product or value chain.

The framework developed for the Ecodesign activities will provide guidelines for LCA and S-LCA, integrating a circular design perspective and needs; the identification of the circular design strategies with more potential for the identified products; the identification of improvement opportunities and measures for the strategies – illustrated with examples and case studies.

Aiming to promote the eco-efficiency of the production system, the design approach will be based on the definition of the value chain, considering the entire life cycle of the product. The identification and quantification of inputs and outputs of materials and energy at all stages, as well as the equipment used, will optimise the system by applying the Ecodesign strategies when possible and applicable, focusing on:

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- The efficiency of the system can also be enabled by the use of digitization/industry 4.0 to monitor and optimise the use of equipment and processes,
- The decision-making regarding one approach could be addressed by the environmental and social LCA and LCC that will be conducted by NTUA plus the calculation of the Ecodesign indicators.

5.1. Ecodesign and Circular economy

The Ecodesign approach was developed and explored in the past decades, focusing on the integration of environmental aspects into the product development process, by balancing ecological and economic requirements at all stages of the product development process, striving for products that make the lowest possible environmental impact throughout their life cycle (British Standards Institute, 2017; EEA, 2017).

The design for the circular economy, or circular design, can be seen as an upgrade and development of the concept in order to attain a higher level of sustainability. It relates to the design and development of products, services and product-service systems that replace the conventional end-of-life concept by closing, slowing and narrowing the resource flows in production, distribution and consumption processes. This is enabled by innovation and novel business and organisational models and aims to accomplish sustainable development through supporting ecosystem functioning and human well-being, and through responsible production and consumption (Schmidt et al., 2020)

Circular economy, in the literature, has many different definitions. In the FRONTSH1P context, the definition adopted is from the KATCH_e European project (Figure 1) as follows:

The circular economy is a system that is restorative and regenerative by intention and Design, which maximises ecosystem functioning and human well-being with the aim of accomplishing sustainable development. It replaces the end-of-life concept with closing, slowing and narrowing the resource flows in production, distribution and consumption processes, extracting economical value and usefulness of materials, equipment and goods for the longest possible time, in cycles energised by renewable sources. It is enabled by Design, innovation, new business and organisational models and responsible production and consumption" (Schmidt et al., 2020).

Disregarding the differences between the concepts, we herewith use the term Ecodesign in a broad sense, i.e., encompassing the circular design approach. In the context of circular economy (and therefore, in the context of the FRONTSH1P project), Ecodesign can be defined as the design and development of products, product-service systems and business models that replace the conventional end-of-life concept by closing (use again), slowing (use

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longer), narrowing (use less) and regenerating (make clean) the resource flows in production, distribution and consumption processes.

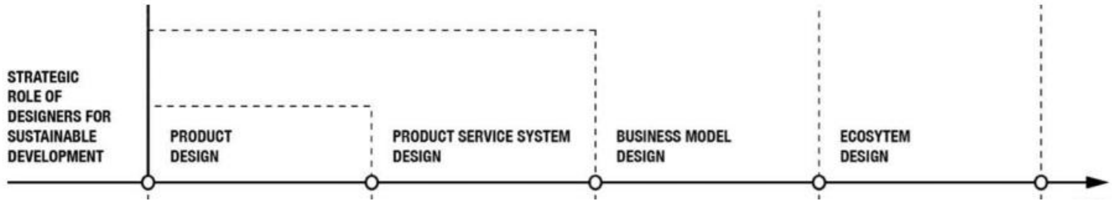

Figure 1. Evolution of the strategic role of designers for sustainable development (KATCH_e, 2019)

As such, Ecodesign presupposes a holistic and systemic approach, which fits perfectly the FRONTSH1P project and the development of the various CSSs of the project, thus promoting new solutions and new business models with greater potential for sustainability and creation of value for the project's stakeholders and for the target regions of its replication.

The Ecodesign approach is crucial to meet the needs and objectives for the transition to a circular economy. On the other hand, a circular business model articulates the logic of how an organization creates, delivers, and captures value to its broader range of stakeholders while minimizing ecological and social costs. Circular business models contribute to a circular economy by adhering to the circular economy’s three fundamental principles (Board of Innovation, 2022):

- Design out waste and pollution,
- Keep products and materials in use,
- Regenerate natural systems.

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6. The CSS within the project

Framework to CSS 3

The United Nations estimates that around 2,212 km^3 of wastewater (WW) are released annually, approximately 56% of all the freshwater used, of which around 80% is discharged without any prior treatment EEA (2017). On the other hand, even with a WW treatment (WWT), only a very small part of the treated water is reused. As it has been estimated that by 2030 the world will suffer a water deficit of 40%, it is urgent to search for sustainable processes enabling the reuse of wastewater WWAP (2012).

Conventional WWT systems consist of an activated sludge process that uses large amounts of energy (up to 0.6 kWh/m^3) to remove compounds from wastewater and release clean water into the environment at a cost of 0.3€/m^3 (Acien et al., 2016).

The main pollutants from the WW side, namely carbon, nitrogen, and phosphorus, are the nutrients from the microalgae side. Therefore, microalgae cultivation from WW allows to the recovery of these nutrients and to the production of up to 1 kg of biomass per m^3 of wastewater at a lower energy consumption and cost (Acién et al. 2018). The robustness of algae and the great capacity to adapt to different climate conditions, such as light intensity and light/dark cycle, pH and temperature, carbon/nitrogen ratio, nitrogen/phosphorus ratio, CO_2 supplementation and cultivation modes can significantly affect the WWT efficiency of microalgae and, consequently, their productivity (Umamaheswari and Shanthakumar 2016). The efficient removal of pollutants/nutrients allows water reuse with the benefit of using the produced biomass/compounds in different markets, such as biofuels, biofertilizers, biostimulants, and high-value chemicals, turning the microalgae into an important skill of circular economy.

However, despite the benefits of microalgae-based technologies *vs* conventional systems, these processes imply a large surface area involved.

Nevertheless, almost all water systems could be treated my using microalgal cultivation as a feasible alternative to the existing WW treatment processes, namely: i) urban WW (secondary and tertiary treatments thereof, including the removal of pharmaceuticals); ii) agriculture WW (e.g., wastes from farming – aquaculture, poultry, swine, cow, dairy, and food processing plants from which removal of antibiotics or pesticides is often needed) and iii) industrial wastes such as flue gas (either on their own or in combination with WW treatment).

In addition to these nutrients, effluents may contain compounds such as pesticides, heavy metals and pharmaceuticals, and the ability of microalgae to metabolize these compounds makes their cultivation even more attractive (Acien et al., 2017).

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Basically, in WWT the symbiosis of the consortium microalgae and bacteria could explain the success of the treatment: in the classical scheme, bacteria are responsible for chemical oxygen demand (COD) degradation to mineral components, consuming photosynthetic O_2 and releasing CO_2, whereas microalgae consume the CO_2 and mineral nutrients to produce microalgae biomass and the O_2 requested by bacteria. This process can replace the energetically expensive treatment steps in a Conventional WW treatment. In this treatment there are must higher GHG (greenhouse gas) emissions due to the need of high energy to agitate the bacteria and from the process, the nutrients are not removed, and there is a production of a bacteria/chemical sludge without any application.

Contrarily, the WWT-based Microalgae there are no need for compulsory agitation due to the symbiosis O_2/CO_2 between microalga-bacteria, and bacteria-microalga, respectively

7. FRONTSH1P Ecodesign Methodology

The methodology used to implement Ecodesign in FRONTSH1P (Figure 2) relies on the analysis of value chain and life cycle consideration. The analysis of the value chains involved in the CSS's and the identification of value losses and opportunities is expected to lead to the identification of new solutions with a high impact in the region, promoting the collaboration and symbiosis within the CSS's and other stakeholders in the region.

The method applied and the definition of strategies guidelines and criteria for the identification of new opportunities with sustainability and circularity potential can be adopted by other regions in Poland and in Europe, fostering the cooperation and the development of new circular solutions in products, services and business models.

Five steps are undertaken in a collaborative way:

- step 1 - the identification of all actors in the CSS's value chain,
- step 2 - the identification of the interactions between them,
- step 3 - the identification of value losses (environmental, economic and social),
- step 4 - the identification of Ecodesign opportunities based on the losses from step 3,
- step 5 - development of guidelines for improvement of the product, service, process and business model.

Therefore, this approach allows for identifying losses and opportunities to retain and capture value, not only understood in a strictly economic sense, but also on environmental value (biodiversity, consumption of resources - water, materials and energy - especially those of concern, such as those scarce or critical, as well as high impact resources, and pollution in all its forms) and social (working conditions, (un)employment, (in)equities, etc.) value.

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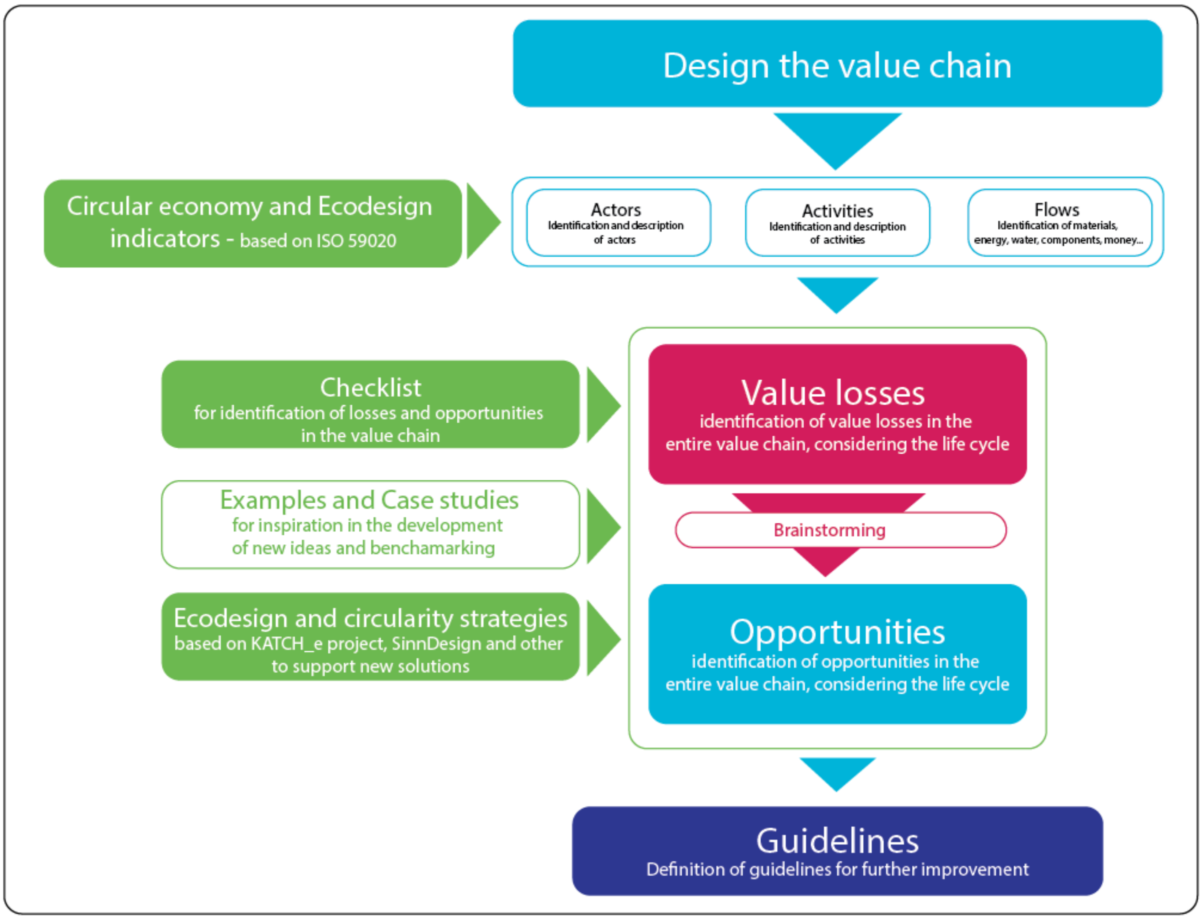

Figure 2. Fronstsh1p Ecodesign and Circularity framework

To carry out this work, specific templates were created for each CSS using the 'Mural' collaborative platform, including an introduction and filling instructions (to make the use of the templates more user-friendly and more systematic). The method and the application in practice are supported by a set of indicators to define and quantify the flows in the value chain, a checklist for the identification of value losses and opportunities in the value chain, a set of examples and case studies collected that are relevant to inspire the work in each CSS, and a group of Ecodesign and circularity strategies and criteria to support the identification of opportunities and the definition of innovative solutions to improve the value chain. These are compiled as a set of guidelines for further development.

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The templates of the collaborative platform MURAL are presented in Figure 3:

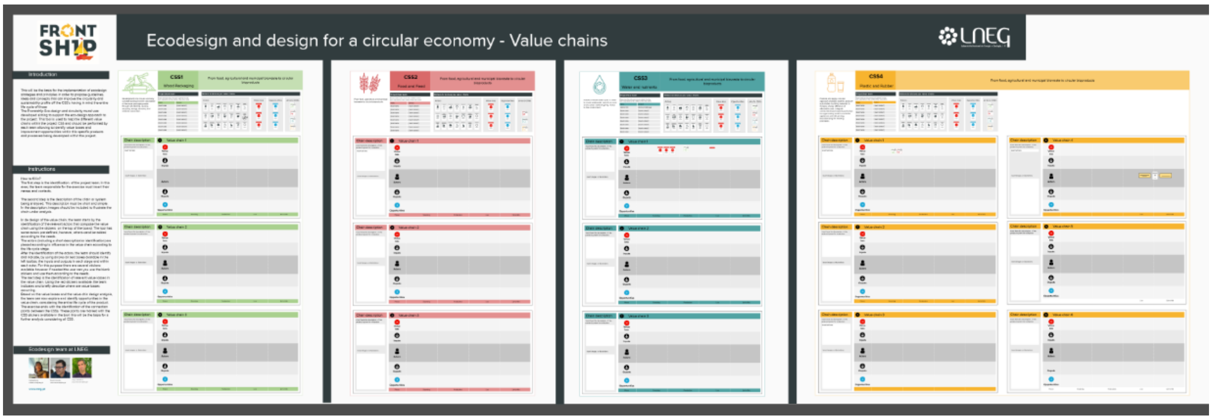


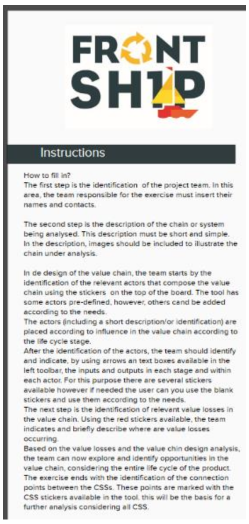
Figure 3. FRONTSH1P Mural

Introduction section (Figures 4 and 5):

This will be the basis for the implementation of Ecodesign strategies and principles in order to propose guidelines, ideas and concepts that can improve the circularity and sustainability profile of the CSS's having in mind their entire life cycle .

The Fronstsh1p Ecodesign and circularity mural was developed aiming to support the ecodesign approach to the project. This tool is used to map the different value chains within the project CSS and should be performed by each team allowing to identify value losses and improvement opportunities within these specific products and processes being developed within the project.

Figures 4 and 5. Introduction in MURAL



How to fill in?

The first step is the identification of the project team. In this area, the team responsible for the exercise must insert their names and contacts.

The second step is the description of the chain or system being analysed. This description must be short and simple.

In the description, images should be included to illustrate the chain under analysis.

In the design of the value chain, the team starts by the identification of the relevant actors that compose the value chain using the stickers on the top of the board. The tool has some actors pre-defined, however, others can be added according to the needs.

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The actors (including a short description/or identification) are placed based on the influence on the value chain according to the life cycle stage.

After the identification of the actors, the team should identify and indicate, by using arrows and text boxes available in the left toolbar, the inputs and outputs in each stage and within each actor. For this purpose, there are several stickers available (Figure 6). However, if needed the user can use the blank stickers and use them according to their needs.

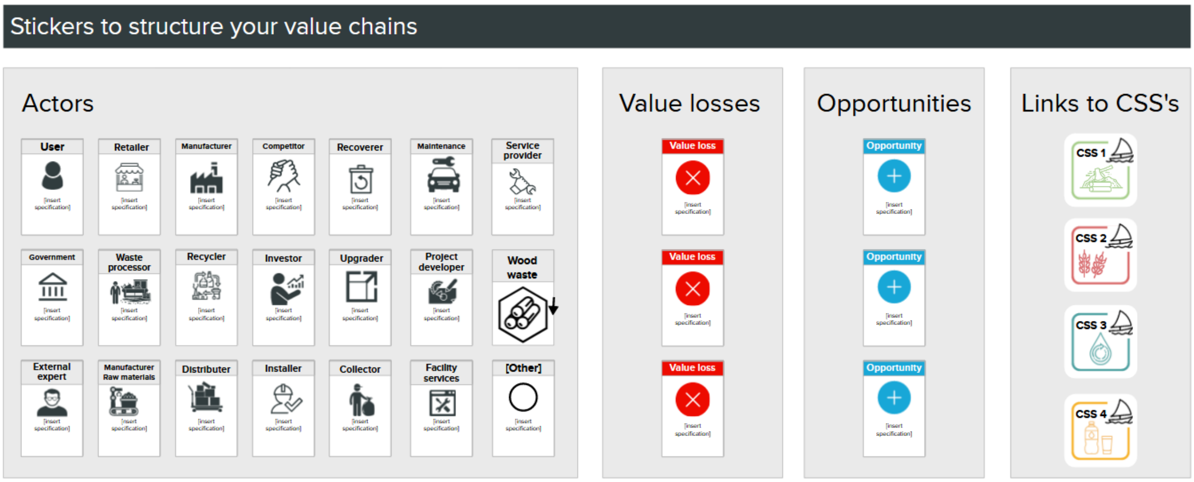

Figure 6. Stickers for value chain definition

The next step is the identification of relevant value losses in the value chain. Using the red stickers available, the team indicates and briefly describes where value losses are occurring.

Based on the value losses and the value chain design analysis, the team can now explore and identify opportunities in the value chain, considering the entire life cycle of the product.

The exercise ends with the identification of the connection points between the CSSs. These points are marked with the CSS stickers available in the tool. This will be the basis for a further analysis considering all CSSs.

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CSS3-specific area in the MURAL platform (Figure 7)

Figure 7. CSS related area in the Mural platform

8. FRONTSH1P Ecodesign and Circular Design Indicators

The Ecodesign and circularity approach is built on the value chain defined within each CSS. In this regard, information and data from each process of product flow must be collected and provided by each CSS team.

8.1. Data needs

System in focus: The CSS as a whole and each actor/activity/process of the value chain, following the life cycle stages: sourcing, production, use, end-of-life, and logistics (packaging, transportation, and storage).

Characterization of the value chain(s) under analysis:

- Identification of the actors in the value chain of the product considering the entire life cycle,
- Relevant information about each actor: description, role in the value chain, sustainability certifications and labels,
- Position of each actor in the value chain

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Data related to inflows, outflows, energy and water (ISO, 2023)

Resource inflow per element/stage of the value chain

- Type and mass of material content in inflow (total quantity),
- Type and mass of reused content in inflow,
- Type and mass of recycled content in inflow,
- Type and mass of renewable content in inflow,
- Type and mass of virgin, non-renewable content.

EXPLANATION:

Resource inflows refer to all resources that flow through the system boundary into the system in focus, except water and energy, which are accounted for separately.

Resource inflows are measured to quantify four types of content: (1) recycled content; (2) reused content; (3) virgin, renewable content and (4) virgin, non-renewable content. The four types of content should be mutually exclusive. (1) to (3) are considered circular, whereas (4) is considered non-circular.

Reused content: a resource inflow is reused content if it has already served a use. It includes materials and parts, but not materials that have been processed through a recycling operation.

Recycled content: material that has been reprocessed from a recovered material, through a manufacturing process, and transformed into a final product or an input to be incorporated in a product. Only pre-consumer and post-consumer materials shall be considered as recycled content.

Renewable material: biomass that is sourced or managed in a sustainable manner, i.e. replenishable at a rate equal to or greater than the rate of depletion and regenerative (i.e., that supports positive outcomes for nature).

Resource outflow per element/stage of the value chain

- Type and mass of material content in outflow (total quantity),
- Type and mass of reusable content in outflow,
- Type and mass of recyclable content in outflow,
- Type and mass of renewable content in outflow,
- Lifetime of the outflow,
- Industry average lifetime of the outflow.

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EXPLANATION:

The resource outflows refer to resources that flow out of the system boundary of the system in focus (i.e., the CSS as a whole and each step of the life cycle, except water and energy, which are accounted for separately. They include secondary materials produced as well as outflows accounting for non-recoverable resources such as hazardous waste and emissions.

The three core circularity indicators for recycling rate, content that is reused and content for renewable recirculation should be mutually exclusive and represent the circular outflows. The remaining are linear outflows.

Outflows from the system that are considered waste or emissions should be identified and calculated separately:

- Solid waste,
- Emissions to water,
- Emissions to air,
- Emissions to land.

The average lifetime of a product or material relative to the industry average is represented by the product durability, compared to the durability of sectoral standard products. It applies to the main output(s) of the CSS(‘s), such as the insulation material (CSS 4).

Reuse content: content from a resource outflow that will be recovered for reuse in the production, maintenance or repair of other resources/products. Typically, this is related to products and/or parts.

Recycled content: content from a resource outflow that is recovered and recycled into secondary material for use as an inflow to the system in focus or by another organization, CSS or region. Typically, this is related to materials.

Recirculation of outflow: outflow content that is recirculated at the end of life for safe return to the biosphere (biodegradation) and meets the qualifying criteria for recirculation (i.e., that originates from a biological source and is suitable for composting, anaerobic digestion or otherwise biodegraded fulfilling criteria set by international guidelines and standards, taking all precautions to avoid negative effects to the environment.

Energy

- Energy inflow (total quantity and type),
- Renewable,
- Energy outflow (quantity and type).

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EXPLANATION:

Energies relevant to a given process or system can be subdivided into:

- Energies derived from renewable energy sources,
- Energies derived from virgin non-renewable resources (e.g., fossil fuels or sources that are not managed sustainably including biomass),
- Energies derived from residual, non-renewable sources.

Water

- Water Inflow from all sources (total volume and type),
- Water inflow from circular sources,
- Water outflow (volume and type).

EXPLANATION:

The circularity indicators for water consider water inflows, water outflows, internal water reuse and water quality.

Water inflows that are from circular sources fulfil all the following quality criteria:

- **Prior use or natural renewability:** non-virgin or recycled water and non-fresh natural sources (e.g. sea or brackish), "rapidly" renewable fresh water sources, such as surface water from areas that are not water-stressed, renewable and harvested rainwater that is completely renewed by precipitation and natural flows;
- **Governance:** strong water governance with equitable and sustainable allocation to all users;
- **Connectivity to discharge:** water from a site that can be discharged back to the original water source once treated.

Water discharged according to circularity requirements: water used in operations that leaves the infrastructure for reuse by another organisation or is returned to the water source at the same or better quality level than extracted. Losses, such as effluents, spillages or evaporation are treated as non-circular outflows.

8.2 Contexts of the benefits for the Lodzkie Region;

Analysis of the value chains of the CSS's and the identification of value losses and opportunities could lead to the identification of new solutions with a high impact in the region, promoting the collaboration and symbiosis within the CSS's and other stakeholders in the region.

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8.3 Context of the benefits for replication regions;

The method applied and the definition of strategies guidelines and criteria for the identification of new opportunities with sustainability and circularity potential can be adopted by other regions in Poland and in the partners countries or other regions in Europe, fostering the cooperation and the development of new circular solutions in products, services and business models.

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9. Relevant circular design strategies

The strategies within the scope of the FRONTSH1P project were selected based on the work and experience in developing approaches to Ecodesign, design for the circular economy and sustainability, particularly following the research developed in the KATCH_e projects and, Sinndesign project, in the CE designer tool, the Ellen MacArthur foundation, among other relevant references in the area (Figure 8).

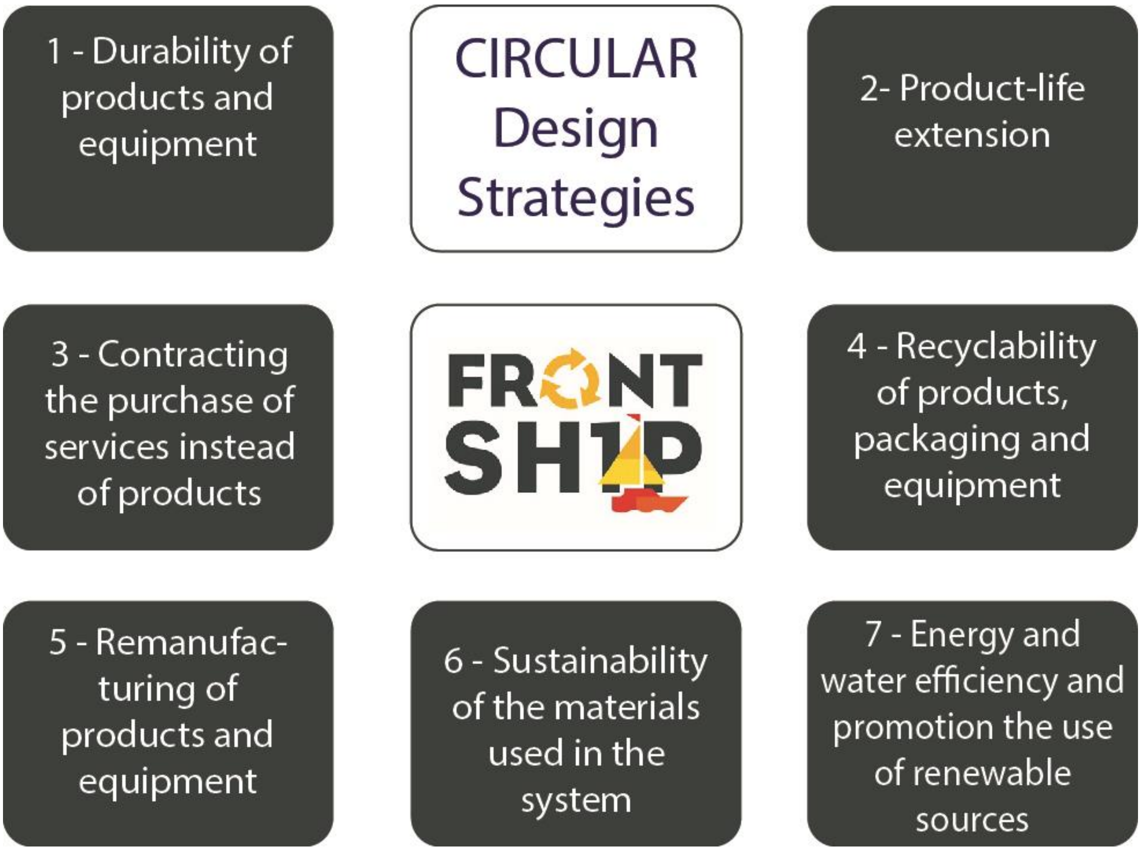

Figure 8. Circular Design Strategies

The strategies are general and will have to be adjusted to the reality and needs of each CSS with the objective of analysing the current profile of the value chains associated with each CSS to identify and propose guidelines for developing new solutions in accordance with the opportunities identified in the approach to the project.

The analysis of strategies and associated criteria, selected and developed based on a design thinking approach with a life cycle perspective, provides practical support for the implementation of Ecodesign and circularity aspects in the value chains analysed.

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The strategies are distributed along a simplified version of the product life cycle, also known as the "Value Hill" (Achterberg et al.,2016) (Figure 9): (i) Up-hill - before use (encompassing extraction of raw materials, manufacturing, assembly and retail), (ii) Top-of-the-hill - during use and (iii) Down-hill - after use (including reuse, refurbish, remanufacture and recycling and eventually final disposal).

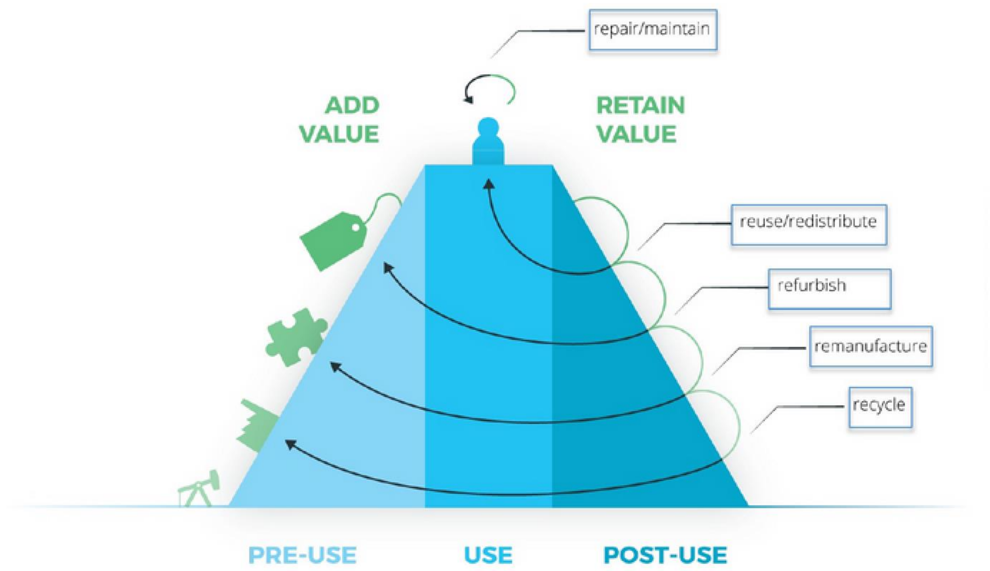

Figure 9. Value Hill" (Achterberg et al.,2016)

9.1. Strategy 1 - Durability of products and equipment

Designing durable products with a long life is linked to ensuring a long utilisation period of products, maintaining their function and service over a longer period of time without loss of performance (Rocha et al., 2020), aiming for a maximum potential lifetime of a product, component or material to perform a required function under intended conditions of use before it becomes obsolete because it cannot fulfil its function (BSI, 2017).

Designing for durability is mainly focused on physical durability, by the development of products that can take wear and tear without breaking down, attained by Design solutions and effective material selection, by designing reliable products that will operate throughout a specified period (Bocken et al., 2016), and by developing product life extension features concerned with an increase in the use period of products, through maintenance, repair and upgrading characteristics defined at the Design stage (Rocha et al., 2020).

The objective of this strategy is to extend the technical, aesthetic and emotional lifetime of the product so that it will be used as long as possible. While this strategy may seem unattractive for companies because they would "sell less", it can be interesting and competitive for certain

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types of products and market segments where high quality and durability are strong sales arguments (Rocha et al., 2015).

Developing durable products that are used and maintained for longer is the counter-strategy to the implanted programmed obsolescence, which is linked to techniques and solutions by which an "organisation seeks to deliberately limit product lifetime in order to increase replacement rate" (BSI, 2017).

CRITERIA for strategy 1

9.1.1 Quality of materials

The selection of the more suitable materials to fulfil the needs of the product and its functions is crucial. The adequate material will promote the durability of the product without creating additional needs in the life cycle of the product.

The quality of the materials in the product should be selected according to the function, considering the implications and trade-offs in the life cycle of the product. For example, the selection of a high-grade and high-quality material for a product that has a short life and will be recycled after a short period of time is not a good option.

9.1.2 Wear-resistant design solutions

Durable products must be resistant to wear and loss of properties over time. The Design and development team must consider these aspects and include solutions to minimise them. This can be achieved by the selection of adequate materials, as well as by the Design attributes of the product. For example, products that are not user-friendly, with complex features tend to have a higher pressure on the structure of the product, leading in most cases to a reduced use period due to wear.

9.1.3 Product-user relation

The challenge is to create products with a stronger emphatic relation with the user. Products that, due to their characteristics, will be attractive for users to purchase, use and maintain (Rocha et al 2015). Designing for attachment and trust or for emotional durability refers to creating products that will be used, liked or trusted longer (Bocken, 2016).

By attaching this emotional aspect to products, it's possible to develop solutions that by exploring its potential, will avoid the replacement of other products, reducing the need of

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producing and placing more products in the market and therefore, the reduction of impacts in the system.

9.1.4 Simplicity principle

The simplicity principle has the potential to increase the durability of the products and it can be implemented in several ways. Simple solutions will promote better use of the product, with a lower margin of error. The simple architecture of the product will promote the reparability and maintenance of the product. Simple and timeless design solutions will avoid disposal due to fashion issues.

9.2. Strategy 2 - Product-life extension

Product life extension is an increase in the utilisation period of products, which results in a slowdown of the flow of materials through the economy (den Hollander & Bakker, 2012).

Designers can and should incorporate features that enable products to serve their originally planned functions over a longer period without losing their performance or that can be maintained or even upgraded to extend their life and maintain the attractiveness throughout time to its user. The extension of life is the counter-strategy to the implanted programmed obsolescence, in which the products are designed to lose part or all of their performance after a specific time.

This strategy is complementary to the promotion of a set of services linked to the product that enables the technological and emotional extension of the function of the product. The design of the product must, from the initial stages of the process, foresee that an action by the user or expert services can be applied in the product or components, to reset or upgrade the function for which the product was designed.

For the effectiveness of the strategy, the development process must take into account simple solutions for disassembly/assembly and modularity/standardisation, to promote easy maintenance and repair, upgrade, and reuse of the product or components (Nancy Bocken 2016; Martijn Gerrittsen 2015).

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CRITERIA for strategy 2

9.2.1 Reparability

Durable products that can be used for long periods of time should rely on the possibility of being repaired easily and at an affordable cost for the user.

In the Design phase, the development team should include features to promote and facilitate the reparability of the product. Features like a Design for easy disassembly, the use of standard components, diagnosis systems, repair information, repair services, etc, should be developed.

9.2.2 Maintenance

Easy and affordable maintenance of the product can have a high impact on the durability of a product. Maintenance involves functional checks, servicing, replacing consumables, cleaning, and other activities. For example, a product that due to its shape or material is difficult or expensive to clean tends to be discarded and replaced easily by the user.

9.2.3 Upgradability

The needs of the users tend to evolve over time, and these new needs can be attained by the replacement of the product with new versions of updated products, or by the upgrade of the current products. In the Circular Economy, to develop sustainable solutions, the product must be in use for the longest possible period of time. This can be attained by solutions to upgrade the existing products by developing solutions that promote the technical or aesthetical upgrade potential, with added value for the user.

9.2.4 Easy replacement of components

If a product is designed so that parts or components are easily replaced in case of damage, maintenance, or need for a technical or aesthetic upgrade, its lifetime will be longer.

9.3. Strategy 3 - Contracting the purchase of services instead of products

"We need to embrace dematerialisation, rethink concepts of ownership and move from resource efficiency to resource sufficiency" Janez Potočnik (Haigh et al., 2021, p.7).

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We need to change the way to fulfil the needs of the users (final users or businesses) in a more sustainable and dematerialized way. If we achieve a reduction in the inputs of the material to fulfil the functions, we can achieve a higher circularity level and create more value.

With a dematerialization focus, the development team must deliver a function with or reduced input of materials, often through moving from physical products to digital alternatives (BSI, 2017), to services or a combination of both. These approaches to product and service development can be attained by strategies like the reuse of products and components, sharing, leasing, repair, refurbishment and recycling of products (EEA, 2017) among other solutions.

The need for the dematerialisation of production and consumption is not likely to happen through efficiency improvements. There is a need for a shift from the current technological paradigm (Idil Gaziulusoy, 2015) through the Design and development of new solutions.

Product/service-systems, as a mean to dematerialize the systems, started to gain momentum due to the high potential for enhanced environmental performance and improved competitiveness (Mcaloone & Pigosso, 2017) and the combination of tangible products within tangible value-added services that lead to dematerialization by reducing the production of waste in the life cycle, by reducing the consumption of resources, and by decoupling the economic growth from environmental impacts, and by creating new revenue streams and extending the residual value of products (Romero & Rossi, 2017).

CRITERIA for strategy 3

9.3.1 Sharing

Sharing of products in order to meet the needs of the users enables an increased use rate of products and services by making possible a shared use or shared ownership among consumers. It enables customers to access a product, rather than owning it, and use it only as needed (BSI, 2017). With this solution, the same product can satisfy the needs of more users which leads to solutions that use fewer resources and can still meet the demands of consumers, or even more.

9.3.2 Leasing

In leasing solutions, the needs of the users, through a contract with a regular fee, can be satisfied by products or services that are leased from a service provider. The provider retains ownership and is often responsible for maintenance, repair, and control (Rocha et al, 2020, BSI, 2017).

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9.3.4 Virtualization

Deliver utility virtually. Replacing physical infrastructure and assets with digital/virtual services offers dematerialization advantages over tangible products, but without reducing the perceived value to the customer (BSI, 2017).

Through digitalisation, everything becomes connected, such as intelligent infrastructure, energy networks, the "Internet of things", and social networks (Dutch Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2016).

9.3.5 Increase service component

For the adoption of dematerialized solutions, the development team must design the system in order to maintain the added value for the users. These solutions, in general, must optimise and increase the services that are provided to the user.

9.4. Strategy 4 - Recyclability of products, packaging and equipment

The objective of this strategy is to develop products in such a way that the materials ("technical nutrients") can be continuously and safely recycled into new materials and products (Bocken et al, 2016). Although in many cases recycling is one of the last strategies to consider in the development of products and services within a circular economy, design for recycling is a strategy to be considered. Developers must understand the process and the conditions for efficient and quality recycling, resulting in quality materials that can be used as valuable input material in the product or service cycle. The potential of recyclability of a product can be enhanced by the easiness of disassembling the product.

Recycling is the process of recovering materials for the original purpose or other purposes, excluding energy recovery. To establish a continuous flow of resources in the technological cycle, the "waste" resources are to be recycled into materials having properties equivalent (or even superior, in a process, called upcycling) to those of the original material (Bocken at al., 2016). In the majority of nowadays recycling operations, what occurs is downcycling (reprocessing into products requiring lower properties), which does not enable a circular flow of resources, but only delays the linear flow of resources from production to waste (McDonough & Braungart, 2002).

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Design for recycling aims at designing products with materials that can be recycled without property losses (and therefore endlessly, in theory).

CRITERIA for strategy 4

9.4.1 Use of recyclable materials

The selection of materials for the production of products should favour the use of materials that can be recycled at the end-of-life. The use of recyclable materials, maintaining the properties and needs of the product reduces the environmental impact of the products.

9.4.2 Choice and variety of materials for easy recycling

The use of different materials in a product conditions its separation for recovery at the end of its life. It is therefore important to take this aspect into consideration in order to optimise the recycling process and ensure that the resulting material is of the best quality possible. The variety of materials used must be minimised and they must be chosen considering also the compatibility for recycling.

9.4.3 Marking materials for recycling

The marking and easy identification of the different materials used in the product facilitate the subsequent sorting and recovery for recycling.

9.4.4 Easy separation of technical from biological materials

An easy separation of the materials from the technical and biological cycles allows a higher valorization of the product according to the respective flows. In a circular economy and sustainability approach, the materials from the biological cycle are non-toxic and can easily be returned to the environment by biodegradation. The technical materials – ores, metals, polymers, alloys, and man-made materials – are designed to be recovered, reprocessed and upgraded.

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9.5. Strategy 5 - Remanufacturing of products and equipment

Through remanufacturing, a used product returns to a "like-new condition"; it is a process of recapturing the value of the material when a product was first manufactured. Remanufacturing results in the reduction of energy and material consumption, and production costs (Gray & Charter, 2007) allowing the manufacturer to increase productivity as well as the profitability of the business. (Fegade, Shrivatsava, & Kale, 2015).

Remanufacture can offer a business model for sustainable prosperity, with reputed double profit margins alongside a significant reduction in carbon emissions and the energy required in manufacturing.

The potential or remanufacture is affected by the physical characteristics specified during the design phase, like the complexity and modularity of the products, the possibility to maintain or adapt technologies, the quality and durability of the materials and the solutions adopted in the product, etc.

Design for Remanufacture is enabled by business models which recognise the benefits of remanufacturing and services like reverse logistics which allow the products to return to the factory at an affordable cost.

Remanufacture views end-of-life products and components as a resource. Promotion of remanufacturing can, therefore, benefit both the economy and the environment. Design for Remanufacture can optimise the process of remanufacturing, increase the practice of remanufacturing and therefore increase the significant economic development opportunities for businesses and people.

This strategy also avoids that valuable material materials and components end on a low-valued valorisation or in a landfill and creates a market for skilled employment and, in principle, is preferable to recycling. The value of materials and components is maintained by returning products to working order, whereas recycling simply reduces the used product to its raw material value (Ijomah, McMahon,Hammond, & Newman, 2007).

Although in theory any product can be remanufactured, the business case, which would make remanufacture economically feasible, varies between sectors and products, and the integration of other considerations like design for disassembly, which enables the process. Design for remanufacturing optimises remanufacture through consideration of both the business model and the detailed product design and must be considered in the initial design of the product (Gray, 2007).

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CRITERIA for strategy 5

9.5.1 Modularity

The adoption of modular solutions can optimise several aspects of the product life cycle. In production, this solution can have benefits at several levels. In production, it can optimise the process, reduce stocks, optimise costs, etc.

9.5.2 Technology integration/stable technologies over the product lifetime

The remanufacturing of a product is facilitated if the technology is maintained or if the product has been designed considering the integration of new technologies at the remanufacturing stage.

9.5.3 Existence of a take-back programme/ reverse logistics

For remanufacturing feasibility, the reverse logistics network must be planned and optimised where the supply chain involvement is a key point. The existence and efficiency of the takeback system is a key issue in this strategy.

9.5.4 Durable and wear-resistant materials and components

The minimization of product wearing, through the use of more resistant materials, components, and structures, contributes to the remanufacturability of the product.

9.5.5 Simplified product architecture

The design of products with reduced complexity allows a higher efficiency in the processes of remanufacturing and other strategies, such as repair, maintenance, etc.

9.6. Strategy 6 - Sustainability of the materials used in the system

Resource efficiency means using the Earth's limited resources in a sustainable manner while minimising impacts on the environment. It allows us to create more with less and to deliver greater value with less input. A reduction of the quantity of materials used in a product or service is possible by implementing efficient strategies in product design. The selection of

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materials and components is a key element in the definition of the potential impact of a product or a service. In the design phase, the design teams can choose materials and components with lower impact.

The properties and functionality of materials are continuously evolving as a result of material innovation and new and more effective material applications. The selection of materials must take into consideration their Sustainability and the designers should take into account the social, economic and environmental aspects throughout the material's life cycle (BSI, 2017).

CRITERIA for strategy 6

9.6.1 Recyclable materials

In a sustainable and Circular Economy approach, to attain the goal of closing material loops, the selection of materials has an important role. The materials selected for a new product must allow that after its use they can be recycled allowing the continuous use of resources.

9.6.2 Recycled materials

In order to maintain the materials in use in a circular loop, the Design solutions must replace virgin materials and consider the selection of recycled materials as much as possible, maintaining the physical properties and attributes of the products.

9.6.3 Renewable materials

The selection of materials to meet the needs of the product must consider the use of renewable materials. These are potentially more sustainable since they are "resources that are able to be renewed or replenished by ecological cycles or agricultural processes at a rate equal to or greater than consumption so that the products and services provided by these resources are not endangered and remain available for future use" (BSI, 2017).

9.6.4 Non-toxic materials

The selection of materials must consider their toxicity. Hazardous substances in the product must be avoided.

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9.6.5 Efficient materials

Sometimes materials may seem not interesting from a Sustainability point of view if considered alone, however they can have a positive influence on the product system and the life cycle. For example, a material can have a high consumption of energy in its production, but its application on a product will highly increase its durability.

9.6.6 Fair materials

Fair materials are materials that are fair from a social point of view. The materials used in a product have a direct impact on the environment and on the people that are linked to those materials in all stages of the life cycle. From the conditions in which they are extracted or produced, transported, the consequences of their use in production, use and in valorisation after the use. Problems like pollution, dangerous working conditions, child labour, etc, are linked to the material's “DNA” and these aspects must be considered in the selection of materials.

9.6.7 Local materials

In the selection of materials, their origin must be a criterion to consider due to the environmental impacts of transport, associated with the consumption of fossil fuels and the emissions. In most cases, the preference should be given to materials that are extracted and processed near the production facilities (Rocha et al., 2015). This aspect also has social impacts that must be considered. Local materials tend to have benefits for local communities.

9.7. Strategy 7 - Energy and water efficiency and promote the use of renewable sources

Like in other areas, product design should take into account the energy and water that the product will need to meet user needs, taking the whole life cycle into account. For energy-using products (e.g. electronics, cars, lighting) and water (e.g. appliances), the use phase may be the most important one; however, for many other non-energy-consuming products (such as furniture or packaging), the manufacturing phase can represent a significant portion of energy consumption.

As renewable energy sources develop and become smaller and more flexible, possibilities for integrating them into product design have emerged. However, until recently, renewable energy technologies have been more or less “pasted” upon the products instead of being integrated

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into the design of the product. It is a big challenge to find the appropriate products or functions for these new technologies and to integrate them into the total design of the product (Mestre & Diehl, 2005).

This strategy thus encompasses energy and water efficiency in the various stages of the life cycle through design options, the use of solutions that incorporate renewable energy and influencing consumer behaviour regarding consumption.

CRITERIA for strategy 7

9.7.1 Low embodied energy materials

In the transition to circular and sustainable solutions, embodied energy should be considered by designers in the development of a product. Embodied energy comprises the energy consumed during the extraction and processing of raw materials, transportation of the raw materials, manufacturing of materials and components and the energy used for various processes during the end of life (Rocha et al 2020). The higher the energy consumption, the higher the environmental impact of the product.

9.7.2 Renewable energy

The Design team should evaluate the consumption of energy along the product's life cycle and prioritize the selection of renewable energy sources.

9.7.3 Reduce energy consumption

The design solutions in the product have an influence on the energy consumption in all stages of the product life cycle.

9.7.4 Reduce water consumption

The design solutions in the product have an influence on water consumption in all stages of the product life cycle.

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9.7.5 Influence sustainable consumer behaviour regarding energy and water consumption

Product design can influence consumer behaviour regarding energy and water towards a more sustainable consumption.

10. Ecodesign and circular economy at FRONTSH1P CSS

10.1. Design of the CSS value chains

Based on the methodology (see chapter 7) developed within the scope of the FRONTSH1P project and using the Ecodesign and circularity tool for value chains created on the collaborative mural platform and the information resulting from the work being developed by the partnership and made available by the various CSSs, the Ecodesign team is working on the representation of the various value chains aiming at the identification of value losses (environmental, economic and ecological), and the identification and exploration of opportunities for improvement in terms of the use of material, energy and water, product design and optimization of existing systems or more circular and sustainable new solutions. This activity is a work in progress in parallel with the collection of data for LCA in the value chains in line with the scenarios defined for carrying out LCAs within the scope of FRONTSH1P.

To illustrate the methodology, an example of the application to CSS 3 is presented below (Figure 10).

In this case, the design of the value chain of a higher TRL compact wastewater management unit for nutrient extraction from agricultural wastewaters and a bigger plant for municipal wastewater both using microalgae to produce circular bio-stimulants from wastewaters and to close the water loop and recycle clean water was developed.

The value chain under development is an example of a circular system. From the beginning, in the initial stage of the project, the flows are optimized and to some extent functioning in a closed system with the recovery and valorisation of waste, emissions, products and sub-products.

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Even in an optimised system, based on the application of the methodology, the Ecodesign team with the CSS developing team were able to identify several value losses with the value chain, such as:

- Value loss in the transport of wastewater for treatment,
- Value loss in the transport of the algae,
- Value loss in the consumption of energy and water,
- Value loss related to the consumption of auxiliary materials in different stages of the process, such as Flocculants, Phosphorus, Nitrogen, etc,
- Value losses in the Transport of Biogas, Biostimulants and Bio fertilizers,
- Value losses related to the waste of packaging resulting from the transport of materials and components,
- Value loss with non-conforming products that may occur within the process.

The analysis of the potential within the value chain allowed also the initial identification of potential opportunities for further developments in order to optimise the system and create value and innovation.

Regarding opportunities to explore, several were already identified:

- Self-production of algae, optimising the system and creating a new business model,
- The recovery of non-conforming products,
- The recovery and reuse of packaging within the system,
- And other opportunities that are under analysis.

This is an example under development, and the team expects to identify more opportunities that allow the development of new innovative and more sustainable solutions to be applied within the project and replicable to other solutions within the project and apart from the project, increasing the potential impact of FRONTSH1P.

The approach is being applied in the remaining CSSs, having as references the scenarios identified and under development.

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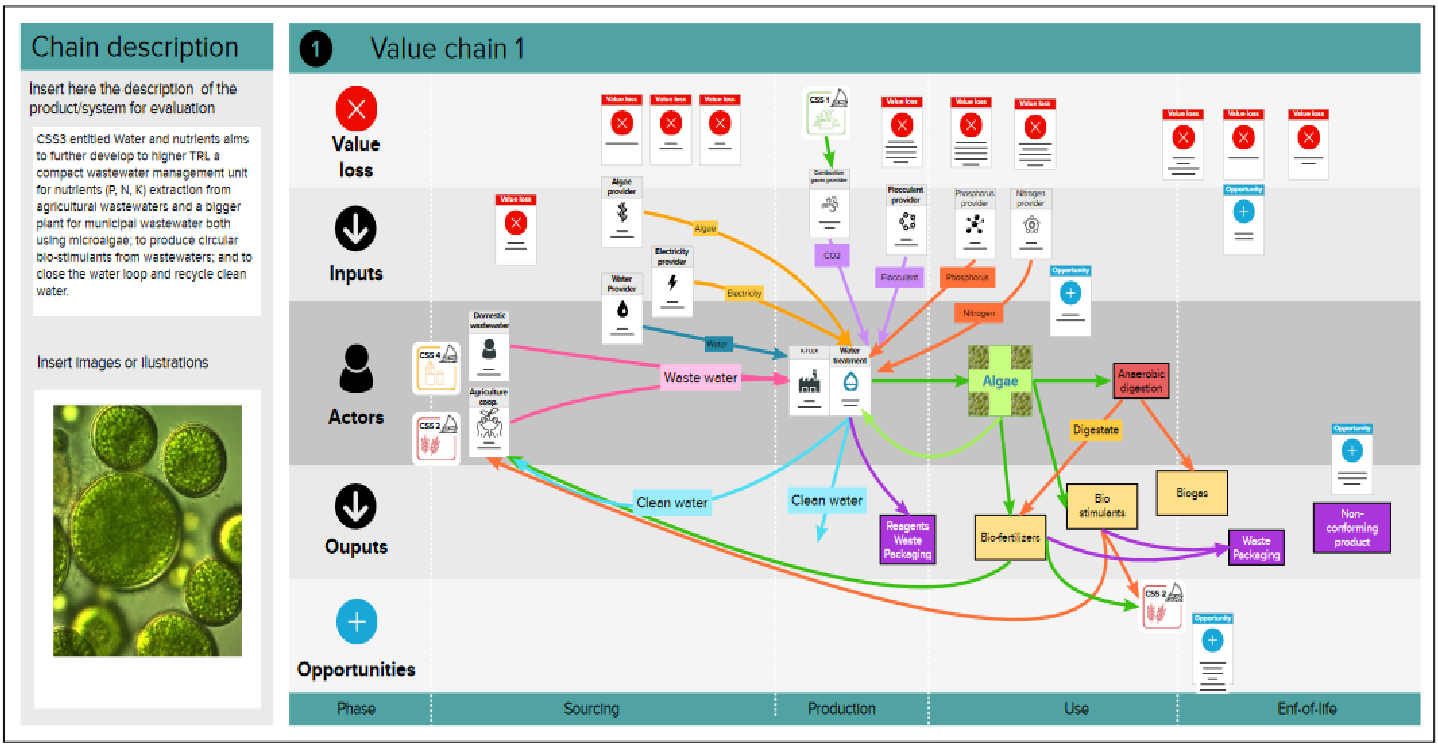

Figure 10. Example of the application of the FRONTSH1P Ecodesign and circularity approach to scenario 1 in CSS3.

10.2. Checklist for value identification - Value loss and opportunities

This checklist supports the identification of ecological, social and economic value losses and opportunities (of value capture/retention) within the four stages of the life cycle: sourcing, production, use and end-of-life. Through a set of questions, it guides the users through a series of aspects that may be overlooked when analysing a value chain, including transport, packaging, etc and considering products, components and by-products. The checklist is supposed to be used after the identification of the actors and the transactions, as a support tool for the next step, and include environmental, social and economic questions.

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Life cycle stage	Questions	Identification	
		Value losses	Opportunities
Sourcing	Does the mining of resources cause damage to nature?		
Sourcing	Are the moned resources scarce or critical raw materials?		
Sourcing	Are labour rights of workers involved in sourcing raw materials respected (salary, wage, working hours, health and safety)?		
Sourcing	Is the mining of resources causing nuisance (noise, odours, visual impact) to the local communities?		
Sourcing	Does the mining of resources create jobs for local communities?		
Sourcing	Are all components included in the product really necessary or could some of them be "avoided"?		
Sourcing	Are materials (e.g. plastic types) combined that can no longer be separated later, so cannot be reused?		
Sourcing	Are materials or components connected to each other in such a way (e.g. glues) that they can hardly be separated?		
Sourcing	Is virgin material used where recycled?		
Sourcing	Is abiotic material used wherever biotic is possible?		
Sourcing	Are there Substances of Very High Concern in the product that make reuse /recycling more difficult?		

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Sourcing	Are critical raw materials used? Has it already been considered whether alternatives are available and/or whether they can be recovered after use?		
Production	Is there a waste of energy and/or water used for production?		
Production	Is the energy used in production sustainably generated?		
Production	Is there any unnecessary "cutting loss" in production?		
Production	Are residual flows in production collected and reused?		
Production	Are all products sold or are there "store daughters" (unsold stock)		
Production	How is the product transported?		
Production	Does the (semi-) product actually have to be produced/assembled at the current location? Or can that also be closer?		
Production	Are labour rights of workers involved in production respected (salary, wage, working hours, health and safety)?		
Production	Is the production causing a nuisance to the local communities (noise, odours, visual impact)?		
Production	Does the production create jobs for local communities?		
Usage	How is the product packaged (primary and secondary) and what happens to the packaging?		
Usage	Is the product also sold via e-commerce and what about deliveries, returns, extra packaging, etc?		

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Usage	Are there many returns due to, for example, "14 days return", DOA, warranty? Is something actively being done with the returns or are they "somewhere"?		
Usage	Are more products delivered than used (e.g. on construction or for an installation)? What happens to the products/components that are not used?		
Usage	Is the product used a large part of the time or is it not fully utilised?		
Usage	Can the product also be used at other times or in other applications and is that not happening now?		
Usage	Does the product itself consume a lot of energy? Is that sustainable energy?		
Usage	Is a lot of energy required in the system (e.g. for servers, cloud storage, peripherals)?		
Usage	Are there any wearing parts in the product and are there maintenance options for them?		
Usage	Is there a difference in lifespan between different components or subsystems?		
Usage	Is the product multi or single-purpose?		
Usage	Can the product or system be easily configured differently if usage changes?		
Usage	Is the product still in use while many more energy-efficient alternatives are available?		
Usage	Do consumers get information on the best way of using the product (incl. health and safety aspects)?		
Usage	How good is the consumers' acceptance of the product?		

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End-of-life	Why does the user stop using the product; • Because it is broken? Can that defect be prevented? Is there a repair service or provider? Are there spare parts? Is the technical lifespan in balance with the economic lifespan? • Because it is a fashion product? • Because the user needs change (quickly)? • Because better products become available through technological development? • Because the user bought it on impulse and actually didn't actually use it? • Because a sub-system, peripheral or accessory has stopped working or is compatible? BV; an e-bike is no longer used because the battery is "exhausted" while the bike is still good.		
End-of-life	Due to amended government regulations? Does the government know what the consequences are for the lifespan of the products?		
End-of-life	Do users know what to do with the product when they stop using it?		
End-of-life	After use, can the user pass the product on to another user or return it for reuse?		
End-of-life	Is there a collection system for the product after use? How high is the collection ratio?		
End-of-life	If the product is used in a production process, has it been developed to be efficient with materials and energy?		
End-of-life	Can the product be easily disassembled? So that, for example, components can be reused or materials purely recovered?		
End-of-life	Are used critical materials recovered? Does metal go to scrap metal?		

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End-of-life	Will the material be reused close to home or far away?		
End-of-life	Is the product designed for remanufacturing/reuse?		
End-of-life	Are labour rights of workers involved in end-of-life processing respected (salary, wage, working hours, health and safety)?		
End-of-life	Is end-of-life processing causing a nuisance for local communities (noise, odour, visual impact)?		
End-of-life	Does end-of-life processing create jobs?		

Source: Adapted from CIRCO.NL

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10.3. Examples and case studies

Examples and case studies of product design and business models that can be used as inspiration for the development of the systemic solutions and for identifying new opportunities for improvement within the project are being collected and analysed.

Some examples that constitute the database of information supporting the Ecodesign and circular economy approach in FRONTSH1P are shown. Till the end of the project, examples will be collected and analysed and constitute an important resource for implementing the project and results in practice.

CSS3 - Water and nutrients - From food, agricultural and municipal biowaste to circular bioproducts

3.1 | "ValSar" project

A team of researchers from the University of Coimbra (UC) is leading a project that aims to develop innovative products from seaweed sargassum.

The project "ValSar: Valorization of Sargasso on the North Coast", financed by European funds, proposes to develop "new biofertilizers and biostimulants (organic natural product, generally poor in nutrients, but rich in bioactive compounds that stimulate natural processes of a crop, such as, for example, the absorption of nutrients, among others) for application in agriculture", as well as "evaluating the potential application of bioactive compounds from sargassum in the pharmaceutical and cosmetics sector", explains the UC, in a statement.

The project, carried out in collaboration with the Higher Agricultural School of Coimbra (ESAC) and the Interdisciplinary Center for Marine and Environmental Research (CIIMAR), and with the support of the municipalities

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	of Vila do Conde and Póvoa do Varzim, aims to identify business opportunities that allow promoting local development within the scope of the maritime economy and consists of three phases: characterization of the sargassum; study, selection and tests with compounds extracted from sargassum; and dissemination of the knowledge produced, not only among the scientific community and the general public but also among investors. To achieve the project's objectives, the team began by seasonally characterizing the diversity, quantity, and chemical and biochemical composition of the algal mixture. This characterization, "allows to identify the different bioactive compounds in sargassum and select the most promising ones for the products we intend to develop, that is, for the valorization we propose". Based on this information, the researchers will now move on to preparing the extracts. For the agricultural sector, the project focuses on the development of a corrective fertilizer substrate, mixing sargassum with "urban solid waste to try to obtain a richer compound, which better enhances crop growth, as these algae contain many mineral compounds, some of which, for example, iodine, which we cannot obtain in a compound based solely on biowaste. We will also develop biostimulants", highlights the researchers. These fertilizers and biostimulants will then be tested on a set of crops of economic interest for the North Coast region, such as cabbage, lettuce, beans and peppers. In parallel, the team will explore another line of products aimed at the pharmaceutical and cosmetics sector. Based on the assumption that algae have many "bioactive compounds", with different biological activities, such as, for example, "antiviral, antibacterial, antifungal and antitumor", the researchers will prepare "extracts and test the bioactive compounds of these extracts in assays of exposure of cells of the immune system and in cell lines that represent the skin: the epidermis and the dermis". According to the researchers, "these tests, which will be able to identify the dermatological potential of sargassum, that is, we will study anti-

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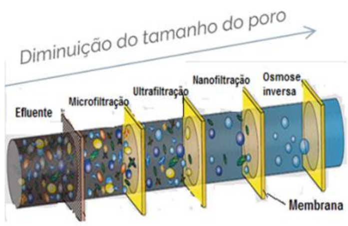
	inflammatory, antioxidant, regenerating, anti-ageing and anti-allergic, among others”.
Measures	● Use of algae for biofertilizers and biostimulants ● Use of algae for the pharmaceutical and cosmetic industry ● Promoting local economy
Source	https://www.uc.pt/valsar/projeto/

3.2 | TECMEM

 	The TecMeM – Tecnologia e membranas em movimento [technologies and membranes in motion] was developed by CEBAL, Portugal (www.cebal.pt). · Value losses: (1) high added-value nutrients from wastewater that results from cheese, wine and olive oil production; (2) water consumption in the production process and (3) wastewater discharge. · Opportunities: recovery of the nutrients; saving of production water; reduction of wastewater production. · Technological solution: sequence of membranes: microfiltration, ultrafiltration, nanofiltration, reverse osmosis. · Obstacles: very small producers with low investment capital, regional dispersion. Ecodesign solution at the service level (figure 1): A mobile membranes unit was designed that provides the treatment service to the producers, with treatment capacities of 6000L/h and 3000 L/h Potential Ecodesign solution at equipment’s level (not known, this is just illustrative): design for repair, design for long-life, modular design, preventive maintenance, eco-efficiency at production and use.
Measures	● Reuse of wastewater from small producers ● Utilization of nutrients from wastewater ● Mobile treatment unit ● Provision of service ● Ecodesign of mobile equipment

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Source	http://www.cebal.pt/index.php/2017-03-31-09-27-00/concluidos/2-uncategorised/134-tecmem

3.3 | Algaecoat

	Researchers from the Center for Marine and Environmental Sciences at the Polytechnic Institute of Leiria (Mare-IPLeiria, PT) in partnership with the company Campotec IN, from Torres Vedras (PT), developed a coating of marine origin: AlgaeCoat. The idea was to find a natural substitute for traditional chemical additives, which would guarantee the preservation of the product for a few days, this substitute was found - in the form of an edible green algae, traditional on the Portuguese coast, from which a bioactive, natural and 100% compound is obtained. % organic, where fruits can be immersed. The Algaecoat project ends up contributing to the circular economy in 3 ways: combating food waste as it allows an extension of the useful life of food; replacing artificial preservation components with a natural component; and valuing a natural, renewable and, above all, locally produced resource (seaweed).
Measures	• Use of algae to produce protective film • Reducing food waste • Replacement of chemical additives with natural components • Valuing natural and local resources
Source	https://www.mare-centre.pt/en/proj/algaecoat

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3.4 | EVOWARE

	Seaweed-based packaging that replaces billions of small bits of plastics with a nutrient boost. Evoware, an Indonesian startup, designs food wrappings and sachets (containing, for example, instant coffee or flavouring for noodles) made out of a seaweed-based material that can be dissolved and eaten. How does this innovation accelerate the transition to a circular economy? The ability of single-use sachets to provide people everywhere with a single dose of instant coffee, shampoo, or medical supplies has many benefits, but because they are so small they often escape collection and end up on beaches, in rivers, or the ocean. Evoware introduces seaweed as a solution, which is a great example of how a biological feedstock can be used for a technical purpose and then safely biodegraded. Evoware plans to increase its local capacity and is positioned to expand internationally since seaweed has the capacity to grow on almost every coastline.
Measures	● Using algae to produce packaging bags ● Reduce the amount of plastic that ends up in the oceans ● Boost the local economy
Source	https://ellenmacarthurfoundation.org/evoware

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11. Guidelines for the CSS

Based on the previous work and activities developed, a set of guidelines will be proposed for implementing circularity in the short/medium term within the scope of the various CSSs.

These are a set of guidelines that result from opportunities with the highest potential for implementation and replication in the Lodzkie region (but not only) in terms of more circular and sustainable solutions in terms of materials (energy and water), Ecodesign and circularity of products and processes, and new business models in a collaborative process with the partnership entities but also with the involvement of regional stakeholders, with a view to the involvement and social development of the region.

The identification of guidelines also results from the satisfaction of defined circular economy indicators which will be one of the ways to evaluate (qualitatively and quantitatively, if possible) the performance of the different solutions and support the decision-making process towards circularity and sustainability.

12. Further development

As mentioned previously in Chapter 2 Scope and Structure, this delivery reflects the ongoing activities under development to support the integration of Ecodesign and circular design aspects in the Circular Systemic Solutions under development in the project.

The activities planned for further development are the following;

- Continuation of mapping the value chains of the different scenarios identified in the CSSs with the collaboration of its leaders, which will allow the identification of relevant value losses and opportunities apart from the ones already identified by the Ecodesign team at LNEG,
- Obtain the LCA and SLCA highlights and cross-reference them with the identification of opportunities in the value chains,
- Qualitative analysis and evaluation of the opportunities identified,
- Identification and analysis of more case studies and examples related to the CSS,
- Identification of the links between CSSs in order to explore potential symbiosis and optimise the systems,
- Definition of Ecodesign and circular Design guidelines for the different scenarios/value chains under analysis in the CSS,
- Establishing the relation of Ecodesign with the tool to be developed in WP7 and data needs in WP2.

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Bibliography

- Achterberg, E., Hinfelaar, J., & Bocken, N. (2016). The Value Hill Business Model Tool : identifying gaps and opportunities in a circular network .
- Bakker, CA., den Hollander, MC., van Hinte, E., & Zijlstra, Y. (2014). *Products that last: Product design for circular business models*. TU Delft Library.
- Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124
- Bocken, N., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a Circular Economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124
- British Standard Institution. (2017). Framework for Implementing the Principles of the Circular Economy in Organizations – Guide (BS 8001:2017).´
- British Standards Institute. (2017). BS 8001:2017 Framework for implementing the principles of the circular economy in organizations – Guide (p. 81). British Standard Institute.
- Camocho, D., Ferreira, A. M., Vicente, J. (2022). Rounding the Vertices - Toolkit for Circular Design. Creative nature hub
- Circle Economy. (2023). The circularity gap report 2023 (pp. 1-64, Rep.). Amsterdam: Circle Economy.
- Den Hollander, & M.,Bakker, C., (2012). A business model framework for product life extension. Proceedings of Sustainable Innovation 2012, Resource Efficiency, Innovation and Lifestyles, 29-30 October 2012, Alanus University, Bonn , pp. 110-118
- Dutch Ministry of Infrastructure and the Environment & Ministry of Economic Affairs. (2016). A circular economy in the Netherlands by 2050, 1–72. Retrieved from https://www.government.nl/documents/ leaflets/2016/09/22/a-circular-economy-in-the-netherlands-by-2050

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- European Environment Agency. (2017). Circular by design – Products in the Circular Economy, EEA Report, No. 6/2017. European Environment Agency. https://doi.org/10.2800/860754

- Fegade, V., Shrivatsava, R. L., & Kale, A. V. (2015). Design for Remanufacturing: Methods and their Approaches. Materials Today: Proceedings, 2(4-5), 1849-1858.https://doi.org/10.1016/j.matpr.2015.07.130
- Gerritsen, M. (2015). Circular Product Design Strategy Criteria and Guidelines. Design for Circular Economy - Demonstrator Sessions.
- Gray, C., & Charter, M. (2007). Remanufacturing and Product Design, Designing for the 7th Generation, The Centre for Sustainable Design, University College for the Creative Arts, Farnham, UK.
- Haffmans, S., van Gelder, M., van Hinte, E., Zijlstra, Y. (2018) Products that Flow - Circular Business Models and Design Strategies for Fast-Moving Consumer Goods, BIS Publishers
- Haigh, L., De Wit, M., Daniels, C., Colloricchio, A., Hoogzaad, J., (2021). Circularity Gap Report. Circle economy. Retrieved from https://www.circle-economy.com https://doi.org/10.2800/860754
- Idil Gaziulusoy, A. (2015). A critical review of approaches available for design and innovation teams through the perspective of sustainability science and system innovation theories. Journal of Cleaner Production, 107, 366–377. https://doi.org/10.1016/j.jclepro.2015.01.012
- Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T. (2007). Development of design for remanufacturing guidelines to support sustainable manufacturing. Robotics and Computer-Integrated Manufacturing, 23(6), 712-719. https://doi.org/10.1016/j.rcim.2007.02.017.
- International Organization for Standardization. (2023). Circular economy - Measuring and assessing circularity performance (ISO/DIS Standard No. 59020)
- KATCH_e (2019) (a), Modules and tools overview, Retrieved from www.katche.eu/wpcontent/uploads/2019/02/KATCH_Modules_Tools_OVERVIEW.pdf
- KATCH_e, (2019a), Knowledge Alliance on Product-Service Development towards Circular Economy and Sustainability in Higher Education. Retreived from www.katche.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037031

- Mcaloone, T. C., & Pigosso, D. C. A. (2017). Sustainable Manufacturing, 99–111. https://doi.org/10.1007/978-3-319-48514-0
- Mcaloone, T., & Pigosso, D., (2017). Sustainable Manufacturing, 99–111. https://doi.org/10.1007/978-3-319-48514-0
- McDonough, W., & Braungart, M. (2002). Cradle to Cradle: Remaking the Way We Make Things (1st ed.). North Point Press.
- Mestre, A., & Diehl, J.C. (2005). Ecodesign and renewable energy: How to integrate renewable energy technologies into consumer products, Fourth International Symposium on Environmentally Conscious Design and Inverse Manufacturing
- Rocha et al. (2015). SInnDesign Background Materials. Sustainable innovation through design. Leonardo da Vinci funded project. Contract nº 2013-1-ES1-LEO05-66254-AN
- Rocha, C. S., Camocho, D., & Alexandre, J. (2020). Design and development. In C. S. Rocha, D. Camocho, J. Sampaio, & J. Alexandre (Eds.), Product-Service Development for Circular Economy and Sustainability Course (pp. 238–293). LNEG - Laboratório Nacional de Energia e Geologia, I.P.
- Rocha, C.S., Camocho, D, Sampaio, J. & Alexandre, J. (Eds.), (2020).Product-Service Development for Circular Economy and Sustainability Course. LNEG - Laboratório Nacional de Energia e Geologia, I.P. ISBN 978-989-675-063-3. 448 p.
- Romero, D., & Rossi, M. (2017). Towards Circular Lean Product-Service Systems. Procedia CIRP,64, 13–18. https://doi.org/10.1016/j.procir.2017.03.133
- Schmidt, K., Bundgaard, A., Hirsbak, S., Rocha, C. S., Camocho, D., & Alexandre, J. (2020). Introduction to the circular economy. In C. S. Rocha, D. Camocho, J. Sampaio, & J. Alexandre (Eds.), Product-Service Development for Circular Economy and Sustainability Course (pp. 2–71). LNEG - Laboratório Nacional de Energia e Geologia, I.P.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037031