OCEAN WISE

Reducing EPS marine litter in the North East Atlantic

Work Package 6. Activity 2

State of the Art Report on Circular and Sustainable Design Methodologies

sustainn

Interreg Atlantic Area

European Regional Development Fund

EUROPEAN UNION

INDEX

CHANGES RECORD

Rev.	Date	Author	Description
Draft 0	30/11/19	Sustainn	Initial Version
Draft 1	28/05/20	Sustainn	2020 Update
Draft 2	16/08/21	Sustainn	2021 Update
0	31/08/22	Sustainn	2022 Update and Final Version

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Aim of this document is to assess and provide an overview of the current state-of-the-art regulations, standards, guidelines, methodologies and tools to design circular and sustainable generic products, and give recommendations to design alternative EPS/XPS products and applications.

This state of the art analysis is focused on the following Oceanwise project priority industries, products and applications:

- Fishing industry packaging (fisheries, aquaculture, sea-food)
- Food goods industry packaging (retail, distribution, supermarket chains, e.g. vegetables, fish, meat, fruit)
- Consumer goods (appliances)
- Outdoor festivals and tourism

This report shows that a lot of references (legislations, standards, methodologies, guidelines, tools) are being developed and a great research activity have been detected in the recent years related to how to design circular and sustainable products.

As a general conclusion, no methodology or reference developed adhoc for EPS/XPS has been found at this moment that could be fully and directly applied to design alternative EPS/XPS products and applications in a structured way, considering the different potential types of application. However, the proposal of Regulation on Ecodesign for Sustainable Products and recent specific guidelines for designing a circular and sustainable packaging should guide the development of circular and sustainable alternative EPS/XPS products and applications.

Finally, this report provides recommendations to the development of a methodology for the design of alternative solutions for EPS/XPS products and applications.

As a general approach, main principles of circular economy have to be translated into specific design for X methodologies and tools, which should be integrated within design processes of EPS/XPS alternatives from their conceptual design stages. Typical Design for X approaches to use for the development of EPS/XPS alternatives are identified, which should be used and particularized depending on the type of business model related in each case (B2B, B2C), the type of application targeted (final consumer packaging, intermediate packaging, etc), the material chosen (technical, biological) and the existing infrastructures throughout the value chain (reverse logistics, waste management, recycling systems) in the target market.

Finally, a specific methodology for the circularity – sustainability assessment of the product, based on the LCSA (Life Cycle Sustainability Assessment) approach integrating circularity principles evaluation, should be used at the end of the conceptual design phase in order to ensure that the technical solution is optimal in terms of circularity and sustainability.

1 AIM

Aim of this document is to assess and provide an overview of the current state-of-the-art regulations, standards, guidelines, methodologies, models and tools to improve circularity of generic products and applications, and specifically for EPS/XPS products and applications. It focuses on the following areas:

- Design & Development processes oriented to recirculation of different product components & materials
- Industrialization & Manufacturing Processes oriented to closed supply chains

Furthermore, the report gives recommendations for **OceanWise** Project to improve circularity of the current EPS/XPS solutions to be analyzed throughout the project, and to design circular alternative EPS/XPS applications.

This document corresponds to the resulting deliverable from **action 6.2 of WP6** (Circularity Indicators and Tools) of **Oceanwise project**, that is *Review of Models to Evaluate and Improve Product/Application Circularity.*

2 SCOPE

First of all, the report describes briefly in *Chapter 5* the Circular Economy context and introduces Oceanwise Project and Work Package 6, oriented to implement the Circular Economy principles and to develop methodologies, indicators and tools to assess EPS/XPS applications.

Chapter 6 describes the state-of-the-art assessment process carried out and *Chapter 7* explains the criteria chosen to assess the different references, such as the applicability scope, design for X approach, life cycle approach, circularity orientation and impacts measurement.

This chapter gathers and evaluates the different references (standards and regulations, guidelines, methodologies and tools, reports, articles, papers and othe references) related to circular and sustainable design for generic systems, products, services, components or materials, and specifically for EPS/XPS products and applications. This analysis is focused on the applicability of the references to the following Oceanwise project priority industries, EPS/XPS products and applications used for:

- Fishing industry packaging (fisheries, aquaculture, sea-food)
- Food goods industry packaging (retail, distribution, supermarket chains, e.g. vegetables, fish, meat, fruit)
- Consumer goods (appliances)
- Outdoor festivals and tourism

Finallly, the report concludes providing recommendations in *Chapter 8* to design circular and sustainable solutions for the EPS/XPS applications targeted in the project.

Annex 1 includes the *Circular & Sustainable Design References Database* built to carry out this state-of-the-art assessment.

3 ACRONYMS

Acronyms used in this document and necessary for its follow-up and understanding are:

CE: Circular Economy
EPS: Expanded Polystyrene
OW: Oceanwise Project
WP: Work Package
XPS: Extruded Polystyrene

4 DEFINITIONS

Below some definitions of specific terms used in this document.

Circularity Assessment. A structured procedure to assess a company, product or service in terms of circularity and sustainability, identifying the environmental and social impact all along its life cycle. It is oriented to maximize the efficiency in the use and exploitation of materials and resources, as well as to minimize and valorize the waste generated, obtaining economical, social and environmentally sustainable products and services.

Circular Economy. A circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. Reference [1].

Design for X Approach. It is a systematic approach for the design of a system, service, product, component or material, oriented to meet an specific goal. In this document "X" refers to integrate different sustainability and circular aspects and design guidelines within the design process (i.e.: for sustainability, for slowing resources loops, for resource conservation, for health and wellbeing).

Life Cycle. Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal. Reference [15].

Life Cycle Costing. Life cycle costing is the process of economic analysis to assess the total cost of acquisition, ownership and disposal of a product. Reference [16].

5 INTRODUCTION

5.1 CIRCULAR ECONOMY CONTEXT

The circular economy is a systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution (see reference [1]). The circular economy is based on three principles, driven by design:

- Eliminate waste and pollution
- Circulate products and materials (at their highest value)
- Regenerate nature

It is underpinned by a transition to renewable energy and materials. A circular economy decouples economic activity from the consumption of finite resources. It is a resilient system that is good for business, people and the environment.

With the Circular Economy Package release in December 2015 (reference [2]) the European Commission showed its commitment to the transformation towards Circular Economy (CE).

CE implementation aims to improve resilience and maintain competitiveness against other markets, especially considering the increasing difficulties of accessing natural resources to develop products and services within the current linear model.

This Circular Economy package included revised legislative proposals on waste, setting clear targets for reduction of municipal and packaging waste by 2030, focused mainly on boosting recycling and reducing landfill. It also promoted turning waste into resources through general requirements for Extender Producer Responsibility (mainly electrical and electronic waste, vehicles, batteries and accumulators).

In particular, it is promoting the transformation of waste into resources through the Producer's Extended Responsibility (PER) concept. Much of the change of regulation (production, consumption and waste) is closely linked to this concept, where the producer of the product is committed to be involved in its prevention and management at the end of its useful life. This concept is already included in European Directives for WEEE's, batteries and accumulators.

Aligned to the Circular Economy package, the European Commission published, on January 2018, a European strategy about plastic waste to protect the planet, defend our citizens and empower our industries (reference [3]), as a part of the transition towards a more circular economy.

This strategy tackles different kind of plastic waste, focusing on single-use plastics. EPS/XPS plastic waste is considered a priority within this strategy, to find alternatives for packaging made of this material.

Succesive initiatives related to the promotion and implementation of ecodesign promotion initiatives have been developed in the recent years, such as the Ecodesign Working Plan 2016-2019, which was focused on improving the energy efficiency of products so far. With this plan, the European Commission explored the possibility of establishing more requirements in areas such as durability, reparability, upgradeability, design for disassembly, information and ease of reuse and recycling.

This working plan led to the development of Sustainable Product Initiative, proposed in 2021, to make sustainable products the norm in the EU, boost circular business models and empower consumers for the green transition.

This initiative finally resulted in march 2022 with the proposal from European Commission for a Regulation on Ecodesign for Sustainable Products (reference [4]) which addresses product design and establishes new requirements for products to be more durable, reliable, reusable, upgradable, repairable, easier to maintain, refurbish and recycle, energy and resource efficient. Final goal is to significantly improve product circularity, energy performance and other aspects of environmental sustainability.

The promotion of PER and ecodesign concepts are really great news, but the implementation on products depends on the transposition of european directives into national standards or laws. This transposition process usually develops quite slowly, so it will take a long time to check the real impact of the measures included to avoid waste generation from design on the market. The global waste problem will not be solved just by improving recycling, waste management and promoting PER.

Meanwhile, the rate of waste generation on the planet is much higher than the speed at which we can turn waste into resource. So, we need to go beyond improving waste management and recycling, exploring all possibilities of recirculation of materials. It is time to think about the best waste, the one that is not designed.

In that regard, methodologies and tools are needed to help the product developer and designer to think about the waste generated during the whole commercialization process and also at the end of the product lifecycle from the early conceptual desig stages, considering the impact of waste management costs within Life Cycle Cost assessment of the products.

It is also needed to bring training, knowledge and culture about thinking on the best waste, down to all the stakeholders aroud the development of a product or service.

Taking other step on the road towards a circular economy, the European Commission published in December 2019 the EU Green Deal (see reference [5]), a new growth strategy and road map that transforms the European Union into a modern, resource-efficient and competitive economy where:

- there are no net emissions of greenhouse gases by 2050
- economic growth is decoupled from resource use

- no person and no place is left behind

Derived from the EU Green Deal, European Commission has released an update of the Circular Economy Action Plan in March 2020 (see reference [6]).

The new Action Plan announces initiatives along the entire life cycle of products, targeting their design, promoting circular economy processes, fostering sustainable consumption, and aiming to ensure that the resources used are kept in the EU economy for as long as possible. It also introduces legislative and non-legislative measures targeting areas where action at the EU level brings real added value.

The new Circular Economy Action Plan presents measures to:

- Make sustainable products the norm in the EU;
- Empower consumers and public buyers;
- Focus on the sectors that use most resources and where the potential for circularity is high such as: electronics and ICT; batteries and vehicles; packaging; plastics; textiles; construction and buildings; food; water and nutrients;
- Ensure less waste;
- Make circularity work for people, regions and cities,
- Lead global efforts on circular economy.

5.2 OCEANWISE PROJECT

OceanWise project aims to jointly develop a set of longterm measures to reduce the impact of expanded and extruded polystyrene (EPS/XPS) products in the North-East Atlantic Ocean. See more information in reference [7].

Based on resource-efficiency participatory methods and circular economy principles, OceanWise will generate new and best practice within sectors considering the use, manufacturing, recycling and uptake of EPS/XPS.

OceanWise deals with marine litter in a circular economy perspective. It is focused exclusively on expanded and extruded polystyrene (EPS/XPS) products and applications with a likelihood to become marine litter. OceanWise wants to approach this issue with a wide-view angle, by putting together a multi-sectoral platform to include Governmental bodies responsible for marine environment management, Industry and other stakeholders, waste management authorities, designers, circular economy modellers, I&D specialists in participatory processes, and end-users. EPS is short for expanded polystyrene, commonly known as plastic foams, and called styrofoam in the U.S. XPS is short for Extruded Polystyrene.

Tangible solutions will be set by addressing the entire life-cycle of EPS/XPS products to achieve transnational sound management of EPS/XPS marine litter in the Atlantic. Based on resource-efficiency, participatory methods and Circular Economy principles, this project will generate new and best practices within sectors using, manufacturing or recycling EPS/XPS.

With this aim, the consortium is intended to explore new ways to:

(i) Identify EPS/XPS products and their source that are more likely to reach the marine environment and impact on its ecosystems;
(ii) Propose and test plausible options (reduce, reuse, recycle, recover) to achieve better environmental outcomes within different sectors;
(iii) Engage producer and designer communities on the sustainability of specific applications and to explore more circular models;
(iv) Develop CE-oriented methodologies to assess new opportunities, barriers and policy options.

This proposal is driven by the EU-Marine Strategy Framework Directive and the OSPAR Convention's Regional Action Plan on Marine Litter.

5.3 WORK PACKAGE 6: CIRCULARITY INDICATORS AND TOOLS

Aim of WP6 is to develop Circular Economy-oriented methodologies to analyze Circularity of current solutions for EPS/XPS (Expanded and Extruded Polystyrene) products and applications (fish boxes, seafood and food packaging) and to select the most sustainable (economic, social, environmental) and circular alternatives.

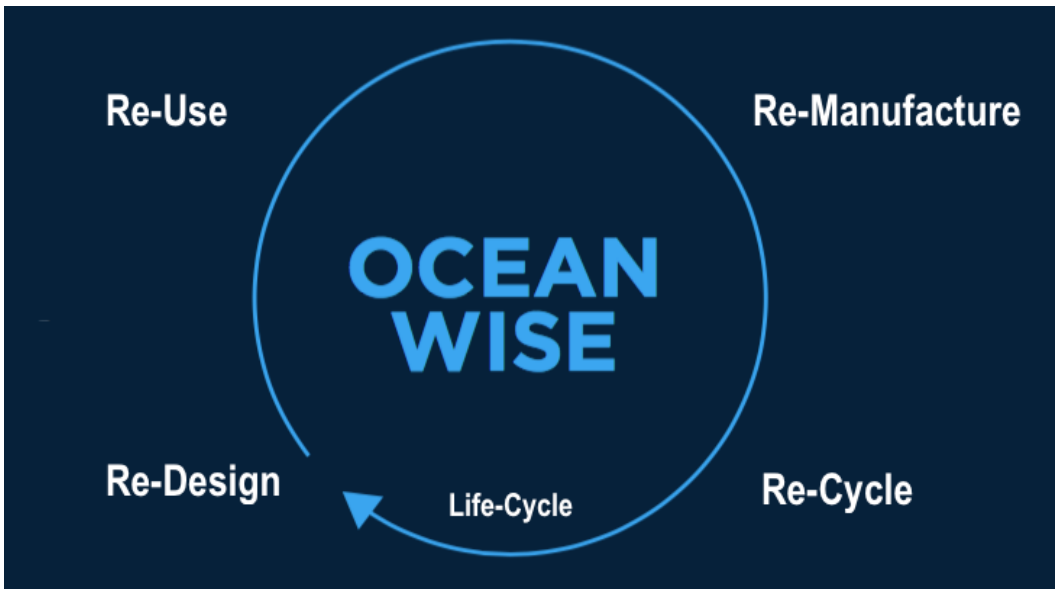


Figure 1. Oceanwise project orientation to Circular Economy

It addresses the following 3 actions:

Action WP6.1: Review of Circularity Indicators/Tools to Evaluate Product/Application circularity

It comprises a state of the art analysis about the different methodologies, tools and indicators to assess circularity of general plastic products and specifically those applicable to:

- Fish boxes and other seafood EPS/XPS packaging
- Food packaging (single use such as hamburgers and supermarket food trays)
- General packaging

Action WP6.2: Review of Models to Evaluate and Improve Product/Application Circularity

It comprises a state of the art analysis of models to improve circularity of products and applications, focusing on the following areas:

- Design & Development processes oriented to recirculation of different product components & materials
- Industrialization & Manufacturing Processes oriented to closed supply chains

Action WP6.3: Circularity Assessment of EPS/XPS Products & Applications

Aim of this action is the development of a methodology to help assessing circularity and sustainability of the life cycle of EPS/XPS products and applications, both current and potential alternative solutions. Ultimate goal of the methodology is to develop the most sustainable (economic, social, environmental) and circular alternatives for the targeted applications.

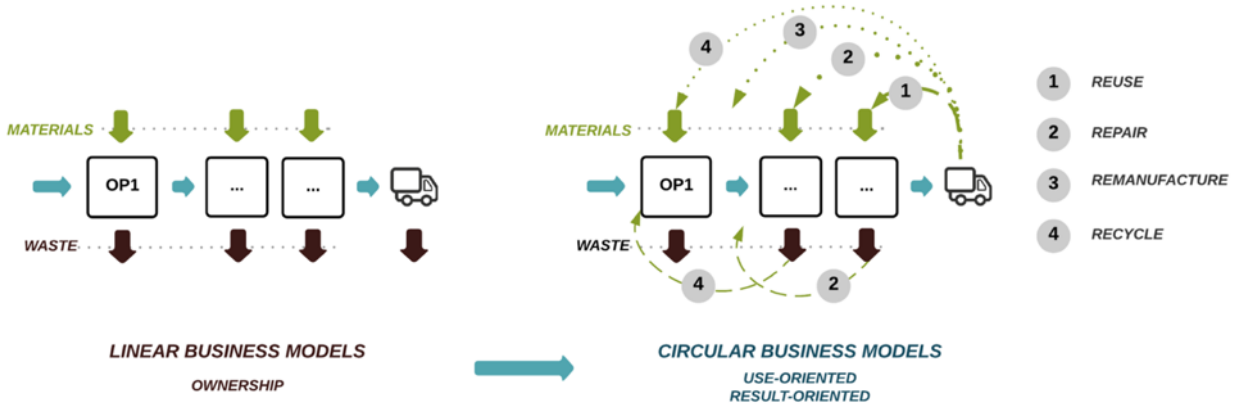


Figure 2. Scheme of the transition from linear to circular economy production models

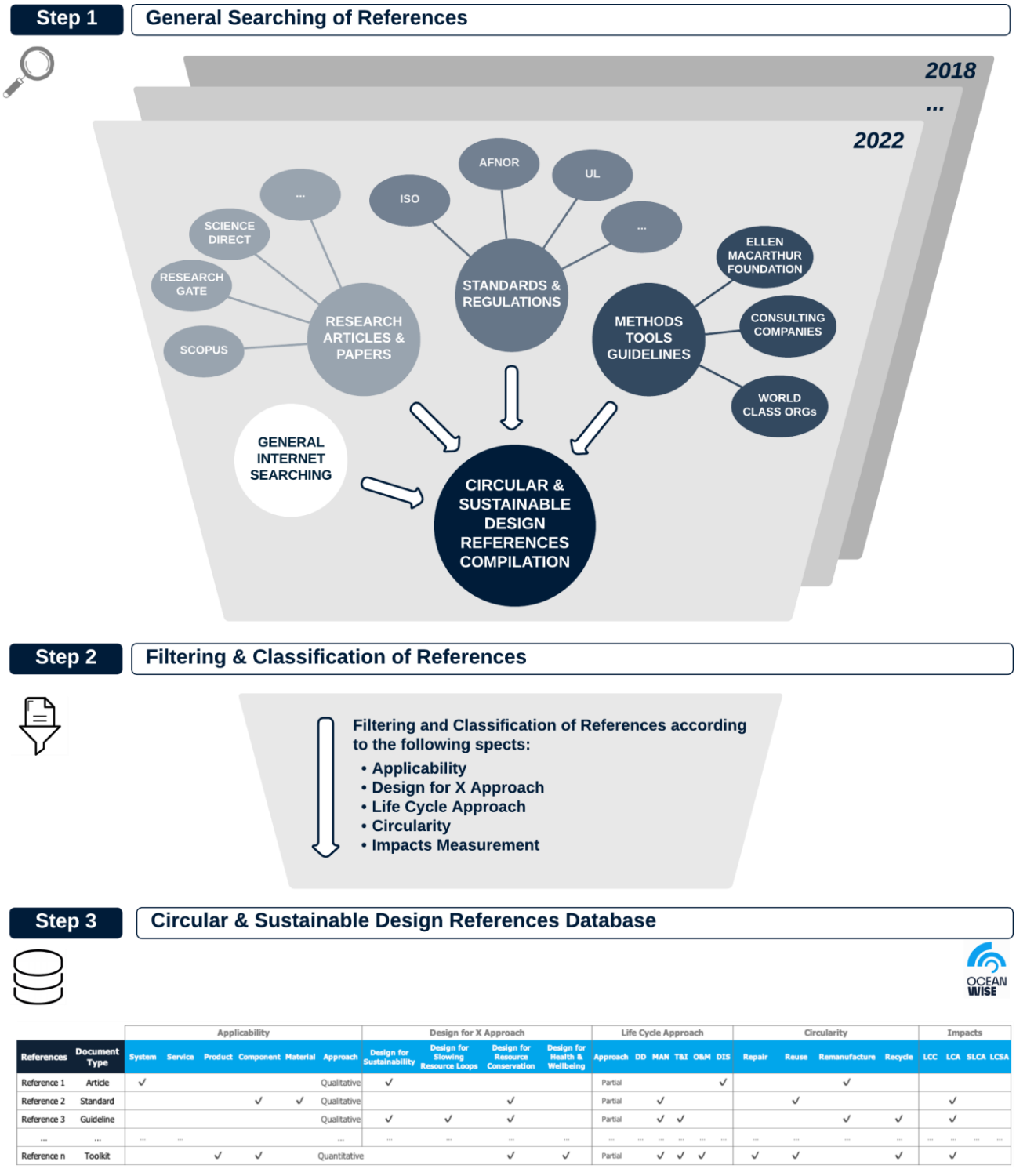
Outputs expected from WP6 are to define methodologies, models and indicators for the transition of Linear to Circular Business Models to:

- Assess and improve Circularity of current EPS/XPS Products & Applications (fish boxes and seafood eps, food packaging, consumer goods packaging)
- Design, develop and select sustainable and circular alternatives
- Methodology for the Circularity Assessment of EPS/XPS Products and Applications

Results of these activities will feed in WP3 action 3 (Capitalization of Circular Economy) to implement and integrate Circular Economy principles within the design and development of EPS/XPS and alternative packaging products and applications.

6 STATE OF THE ART REVIEW PROCESS

An overview of the Circular & Sustainable Design state of the art review process is showed in the following figure.



		Applicability						Design for X Approach				Life Cycle Approach					Circularity				Impacts			
References	Document Type	System	Service	Product	Component	Material	Approach	Design for Sustainability	Design for Slowing Resource Loops	Design for Resource Conservation	Design for Health & Wellbeing	Approach	DD	MAN	T&I	O&M	DIS	Repair	Reuse	Remanufacture	Recycle	LCC	LCA	SLCA	LCSA
Reference 1	Article	✓					Qualitative	✓				Partial					✓			✓					
Reference 2	Standard				✓	✓	Qualitative			✓		Partial		✓					✓			✓			
Reference 3	Guideline						Qualitative	✓	✓	✓		Partial		✓	✓					✓	✓	✓			
...	...	...	...				...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Reference n	Toolkit			✓	✓		Quantitative			✓	✓	Partial		✓	✓	✓		✓	✓		✓	✓			

Figure 3. Overview of Circular & Sustainable Design State of the Art Review Process

Step 1: General Searching of References

The aim of step 1 is to do a general searching of references related to a circular and sustainable design of systems, services, products, components and materials.

Searching is focused on the following sources:

- General internet searching

Initially, the general searching has been done through the following main keywords (as showed in Figure 4): "ecodesign", "design for environment", "design for sustainability", "design for circular economy", "circular design" and "human-centered design", and other different specific design for X approaches related to sustainability and circular economy.

More specifically, as described below, those keywords have been used in combination with different type of documents, such as research articles, papers, standards, regulations, guidelines, methodologies, and tools.

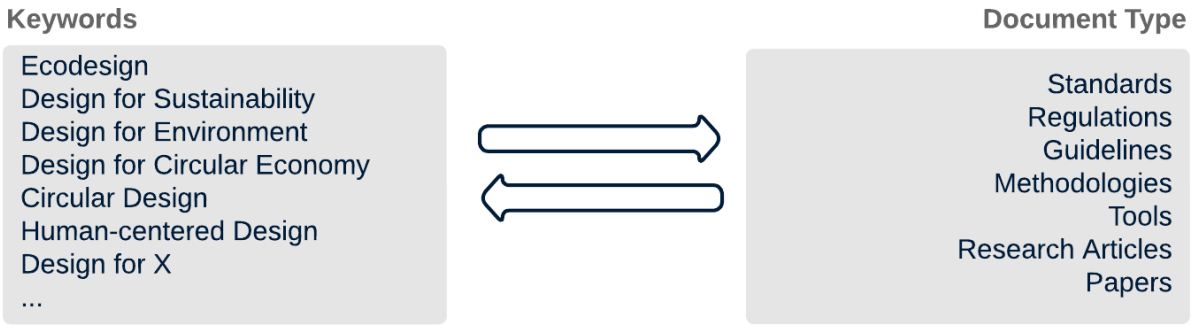


Figure 4. General searching approach. Keywords vs Documents Type

As a starting point, the related documents and fundamental references derived from the circular economy plans and the European Green Deal from European Commission described in section 5.1 will be analyzed.

- Research articles and papers

A general literature review of research articles and papers with the same combination of keywords described above has been conducted using mainly academic literature databases, such as:

  - Scopus database, from Elsevier (reference [8])
  - Researchgate (reference [9])
  - ScienceDirect (reference [10])
  - Web of science (reference [11])
  - Wiley online library (reference [12])
  - MDPI (reference [13])

- Standards and regulations

As the transition towards the Circular Economy is progressing, standards and regulation are being developed to guide and help implementing worldwide its principles in countries, regions and organizations. So, a specific search has been conducted, mainly focused on european directives as well as on international and national standardization, certification and regulation bodies, such as ISO, EN, AFNOR, AENOR, BSI and UL.

- Guidelines, methodologies and tools

Finally, a particular searching for specific methodologies, tools and indicators related to the implementation of circular economy has been done on worldwide circular economy reference organizations (such as Ellen Macarthur Foundation), specialized top consulting companies and world class organizations working and promoting sustainability.

Step 2: Filtering & Classification of References

Aim of this step is to review, filter and classify all the references collected from the different information sources, according to the following aspects:

- Applicability
- Design for X Approach
- Life Cycle Approach
- Circularity
- Impacts Measurement

These aspects have been defined to evaluate the different circular and sustainable design references references found. Rationale and a detailed description of these aspects are given within subchapter 7.1.

Step 3: Circular & Sustainable Design References Database

At this step, all the references found are listed and organized in the *Circular & Sustainable Design References Database*, which provides a practical overview of their applicability to Oceanwise project, identifying advantages and drawbacks and extracting the main concepts to be applicable to design circular and sustainable solutions for the EPS/XPS applications targeted in the project.

Following picture shows a schematic representation of the *Circular & Sustainable Design References Database* (see reference [14]), included in Annex 10.1.

		Applicability					Design for X Approach				Life Cycle Approach						Circularity				Impacts			
References	Document Type	System	Service	Product	Component	Material	Design for Sustainability	Design for Slowing Resource Loops	Design for Resource Conservation	Design for Health & Wellbeing	Approach	DD	MAN	T&I	O&M	DIS	Repair	Reuse	Remanufacture	Recycle	LCC	LCA	SLCA	LCSA
Reference 1	Article	✓					✓				Partial					✓			✓					
Reference 2	Standard				✓	✓			✓		Partial		✓					✓				✓		
Reference 3	Guideline						✓	✓	✓		Partial		✓	✓					✓	✓		✓		
...	...	...	...				...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Reference n	Toolkit			✓	✓				✓	✓	Partial		✓	✓	✓		✓	✓		✓		✓		

Table 1. Circular & Sustainable Design References Database

Since there are a lot of initiatives running and a lot of researching about circular economy implementation, General Searching of References (Step1) has to be repeated all along the Oceanwise project development (from 2018 to 2022, as showed in Figure 3).

Therefore, the *Circular & Sustainable Design References Database* is to be updated periodically throughout the project development to have the most real picture of the state of the art on standards, regulations, methodologies, guidelines, tools, papers and articles related to circular and sustainable design. See an overview of the contents of the database in the following figure.

Figure 5. Index of contents of Circular & Sustainable Design References Database

7 STATE OF THE ART ANALYSIS

The following subchapters describe the analysis of the different circular and sustainable design references found in Step 1 described above.

First of all, analysis criteria is described, defining all the aspects considered for filtering and classification of all the references.

Then, an overview of the state of the art analysis is given based on the analysis criteria defined.

Finally, the most relevant references applicable to *Oceanwise* project are studied in detail in subchapter 7.2, aiming to extract, in subchapter 7.3, the main concepts about design for X approach, life cycle approach, circularity and impacts measurement to consider to design circular and sustainable solutions for the EPS/XPS applications targeted in *Oceanwise* project.

7.1 ANALYSIS CRITERIA

Analysis criteria is based on a set of aspects used to filter, classify, study and evaluate the different references found related to circular and sustainable design. These are the aspects defined:

- Document Type
- Applicability Scope
- Design for X Approach
- Life Cycle Approach
- Circularity
- Impacts Measurement and Indexes

A detailed description of them is given in the following sections.

7.1.1 Document Type

These are the different types of documents among all the references found.

- **Regulation:** a technical regulation is a Government document that lays down product characteristics or their related processes and production methods, including the applicable administrative provisions, with which compliance is mandatory. No consensus is necessary for establishment of the regulation.

- **Standard:** a document approved through consensus by a recognized body (can be a standardization), providing, for repeated an common use, rules or guidelines for products or related processes and production methods, with which compliance is not mandatory.

- **Guideline:** a document defining, describing a method or guiding to carry out a process or analysis of any kind (assessment, design, calculation..). It indicates policies, standards, or procedures for how something should be done or accomplished.

- **Methodology:** a system of methods, practices, techniques, procedures, and rules used in a particular area of study or activity.

- **Tool:** something tangible, such as a template or software program, used in performing an activity to produce a product or result.

- **Analysis Report:** a document, in this context, developed by a relevant administration, association or company analyzing aspects related to circularor sustainable design.

- **Research article or paper:** an article or paper developed as a result of a specific research, of any kind (argumentative, analytical, comparison, etc).

7.1.2 Applicability Scope

In this area, different aspects are defined to evaluate the application scope of the different references, as well as qualitative or quantitative approach.

- **Application Scope**. Scope of application of the references from system to material level, addressing the following type of "objects":

    - System, understood as a construct or collection of different elements that together produce results not obtainable by the elements alone
    - Service
    - Product
    - Component
    - Material

- **Certifiability**. It evaluates if applying a reference is verifiable and certified from a third party or certification body.

7.1.3 Design for X Approach

In this area, different aspects are defined to evaluate the design approach considered within the different references. The different "Design for X" approaches are defined considering the following aspects:

- Main 3 principles of Circular Economy, defined in the Circular Economy System Diagram, from Ellen Macarthur Foundation (see reference [1]), that are:

- **Principle 1**: Preserve and enhance natural capital by controlling finite stocks and balancing resource flows, meaning that technology and processes are chosen wisely according to their use of renewable or better-performing resources.
- **Principle 2**: Optimize resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles; meaning designing for remanufacturing, refurbishing and recycling to keep technical components and materials circulating in the economy, preserving embedded energy and other value. It also refers to encouraging biological nutrients to re-enter the biosphere in the safest way possible to become valuable feedstock for a new cycle.
- **Principle 3**: Foster system effectiveness by revealing and designing out negative externalities; this includes reducing damage to human utility, such as food, mobility, shelter, education, health and entertainment, and managing externalities, such as land use, air, water and noise pollution, release of toxic substances and climate change.

- Designing sustainable solutions must consider impacts on the following 3 dimensions from the beginning:
  - Economical
  - Social
  - Environmental

- Categorization of design for sustainability approaches according to "Circular design framework" extracted from Table 2 of reference [34] as shown in Figure 6.

DfX Approach	Circular Design Strategy	Design Focus	DfX Method/Tool	Literature Sources
Design for resource conservation	Design for circular supplies	Design for closing resource loops	Design for biodegradability	Bocken et al. [10]; McDonough and Braungart [7]
			Design with healthy/smart processes/materials	Bocken et al. [10]; Benyus [40]; McDonough and Braungart [7]
	Design for resource conservation	Design for reduce resource consumption	Design for production quality control	Boothroyd [26]; Allwood et al. [16]
			Design for reduction of production steps	Allwood et al. [16]; Vezzoli and Manzini [13]
			Design for light weighting, miniaturizing	Allwood et al. [16]; Vezzoli and Manzini [13]
			Design for eliminating yield loses/material/resources/parts/packaging	Allwood et al. [16]; Vezzoli and Manzini [13]
			Design for reducing material/resource use	Ashby and Johnson [21]; Allwood et al. [16,17]; Clark et al. [14]; Vezzoli and Manzini [13]
Design for slowing resource loops	Design for long life use of products	Design for reliability and durability	Design on demand or on availability	Bhamra and Lofthouse [12]; Chapman [27]; Clark et al. [14]; Vezzoli and Manzini [13]
			Design the appropriate lifespan of products/components	Bakker et al. [23,24]; Bhamra and Lofthouse [12]; Bocken et al. [10]; Chapman [27]; Clark et al. [14]; Cooper [29]; Lofthouse [35]; Van Nes and Cramer [39]
		Design for product attachment and trust	Create timeless aesthetics	Bakker et al. [23,24]; Bhamra and Lofthouse [12]; Bocken et al. [10]; Chapman [27]; Lofthouse [35]
			Design for pleasurable experiences	Bhamra and Lofthouse [12]; Bocken et al. [10]; Chapman [27]; Lofthouse [35]
			Meaningful design	Bhamra and Lofthouse [12]; Bocken et al. [10]; Chapman [27]; Clark et al. [14]; Lofthouse [35]
		Design for extending product life	Design for repair/refurbishment	Bakker et al. [23,24]; Bocken et al. [10]; Chapman [27]; Kimura et al. [33]; Van Nes and Cramer [39]
			Design for easy maintenance, reuse and repair	Bakker et al. [24]; Bocken et al. [10]; Bogue [25]; Chapman [27]; Johansson [32]; Edwards, [30]; Van Nes and Cramer [39]
			Design for upgradability and flexibility	Bakker et al. [23]; Bocken et al. [10]; Bogue [25]; Chapman [27]; Johansson [32]; Edwards [30]; Van Nes and Cramer [39]
		Design for dematerialising products	Design for product-service systems	Bakker et al. [24]; Clark et al. [14]; Morelli [36]; Sundin and Lindahl. [38]; Tukker [50]; Vezzoli and Manzini [13]
			Design for swapping, renting and sharing.	Bakker et al. [24]; RSA [2]; Tukker [50]
	Design for multiple cycles	Design for resource recovery	Design for easy end-of-life cleaning, collection and transportation of recovered material/resources	Vezzoli and Manzini [13]
			Design for cascade use	Accorsi et al. [22]; Vezzoli and Manzini [13]
			Design for (re)manufacturing and dis- and re-assembly	Bakker et al. [24]; Bocken et al. [10]; Bogue [25]; Chapman [27]; Edwards [30]; Hatcher et al. [37]; Johansson [32]; Kimura et al. [33]; Sundin and Lindahl [38]; Van Nes and Cramer [39]
			Design for upcycling/recycling	King et al. [34]; Vezzoli and Manzini [13]
Whole Systems Design	Design for systems change	Design to reduce environmental backpacks	Design for the entire value chain	Charnley et al. [6]; Chertow and Ehrenfeld [18]; Claypool et al. [28]; Vezzoli and Manzini [13]; Wells and Seitz [45]
			Design for local value chains	Wells and Seitz [45]; Vezzoli and Manzini [13]
		Design for Regenerative Systems	Design for biomimicry	Benyus [40]; Nagel et al. [42]; Schenkel et al. [43]; Vincent et al. [44]
			Design for biological and technical cycles	Bocken et al. [10]; McDonough and Braungart [7]; Braungart et al. [41]

Figure 6. Design for X approaches framework

So that, summarizing and integrating all these aspects, the first level "Design for X" approaches analyzed in this document are:

- Level 0: Design for Sustainability, if a reference considers sustainability, ecodesign, or environmental impact reduction as a general goal of the design. It is considered herein this document at the top of the hierarchy, as the Level 0 approach, and must contain the following Level 1 approaches.
- Level 1:
  - Design for Resource Conservation. This strategy focuses on both the technical and biological cycles and uses a preventative approach in which products are designed with the minimum of resources in mind.
  - Design for Slowing Resource Loops. Through the design of long-life goods and productlife extension (i.e. service loops to extend a product's life, for instance through maintenance, repair), the utilisation period of products is extended, resulting in a slowdown of the flow of resources.
  - Design for Health and Wellbeing, related to develop solutions by involving the human perspective in all steps of the problem-solving process directly related with health and wellbeing influences of the product/service.

Sublevels of these approaches considered in the state of the art review are showed in the following table.

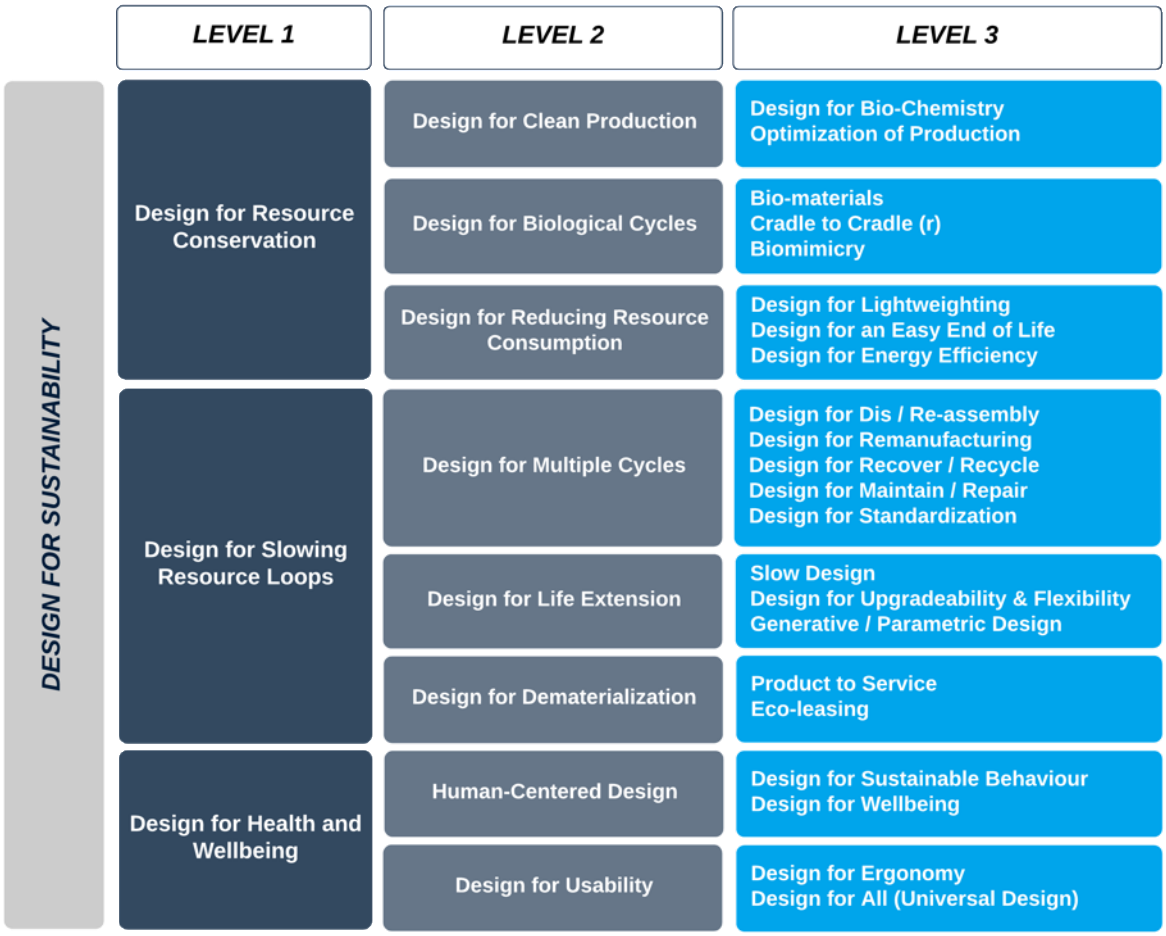


Figure 7. Design for X approaches summary considered in the state of the art analysis

A brief description of these Design for X approaches is included in Annex 10.2.

7.1.4 Life Cycle Approach

The following aspects defined in this area regards to the life cycle approach of the different references.

- **Life Cycle Scope**. Life cycle approach of the different references is evaluated

  - Partial approach. It refers to a particular or to several phases of the life cycle
  - Full approach. It refers to a full life cycle approach

- **Life Cycle Phases**. The phase or phases of life cycle addressed within the different references are evaluated.

According to ISO 14040 (see reference [15]), life cycle phases have to include from raw material acquisition through production, use, end-of life treatment, recycling and final disposal.

Evaluation of the product life cycle phases addressed within the references is done according to the definition of product life cycle phases given in International Standard IEC 60300-3-3 (see reference [16]). It is an application guide to carry out life cycle costing of a product, defining a clear scope of the different life cycle phases in terms of costs, as follows.

- Concept and Definition (CD). Concept and definition phase comprises various activities conducted to ensure the feasibility of the product under consideration, such as market research, preparation of a requirement specification of the product or product concept and design analysis.

- Design and Development (DD). Design and development phase is attributed to meeting the product requirements specification and providing proof of compliance, including activities such as:

  - design engineering, including reliability, maintainability and environmental protection activities,
  - prototype fabrication,
  - testing and evaluation,
  - producibility engineering and planning,
  - vendor selection, and
  - demonstration and validation

  In the *Circular & Sustainable Design References Database*, CD and DD phases are mixed together into the phase CDD, aiming to evaluate if conception, definition, design and development phases of a product are addressed.

- Manufacturing (MAN). Manufacturing phase refers to making the necessary number of copies of the product or providing the specified service on a continuous basis. Main activities included are:

  - construction of facilities,
  - supply chain development and acquistion of bill of materials
  - fabrication (labour, materials)
  - testing of manufacturing processes
  - production management and engineering,
  - facility maintenance,
  - quality control and inspection,
  - packaging, storage, shipping and transportation

- Transport (T). It refers to all activities related to transportation to distributors or final user.

- Installation (INS). It refers to all activities related to the assembly on site, installation, check-out and commisioning of product at the final destination. Main activities included are:

- testing of installation processes
- assembly, installation and checkout,
- commissioning
- quality control and inspection,

In the *Circular & Sustainable Design References Database*, T and INS phases are mixed together into the phase T&I, aiming to evaluate if transport and installation phases are addressed within every reference.

- Operation and Maintenance (O&M). This phase comprises all the activities related to operation, maintenance (predictive, preventive and corrective) and supply support of products throughout the expected life of the system/product.

- Disposal (DIS). This phase refers to all activities related to decommissioning and disposal of older versions of the products, including system shutdown, disassembly and removal, recycling or safe disposal.

7.1.5 Circularity

In this area, different aspects are defined to assess if the different references evaluate the circularity of a product and its components, following the 4 main recirculations:

- Repair: if the product or its components go back to the manufacturer for repair
- Reutilization: if the product or its components are to be reused
- Remanufacture: if the product or its components come back to the manufacturing process for the rebuilding of a product to specifications of the original manufactured product using a combination of reused, repaired and new parts
- Recycle: if the disposed materials composing a product or component are reprocessed to use them in the same or other manufacturing processes or applications

7.1.6 Impacts Measurement Indexes

In this area the following aspects are assessed related to economic, environmental and social impacts.

- **Costs impact (LCC)**. It evaluates if a reference addresses the impact costs all along the life cycle
  - Partiallly
  - Full Life cycle cost approach (LCC), which is the cumulative cost of a product over its life cycle

- **Environmental impact (LCA)**. It evaluates if a reference addresses the environmental impact all along the life cycle
  - Partiallly
  - Full Life cycle approach (LCA)

- **Social impact (SLCA)**. It evaluates if a reference addresses the social impact all along the life cycle
  - Partiallly
  - Full Life cycle approach (SLCA)

- **Global sustainability or circularity index**. It evaluates if a reference addresses or defines an overall index to assess sustainability (economical, environmental and social) or circularity of the object analyzed.

7.2 ANALYSIS OVERVIEW

This point shows a general overview of the state of the art review analysis carried out and the detailed analysis of all the available circular and sustainable design references following the analysis criteria defined previously, identifying advantages, drawbacks and applicability to EPS/XPS products and applications.

A total of 86 relevant references have been selected related to the combination of searching terms defined in chapter 6, within this state of the art review of circular & sustainable design references.

Following the steps defined before in the analysis overview, general findings related to the different criteria analysis aspects defined in sub-chapter 7.1 are described within the following sections.

7.2.1 Document Type

There is a great research activity in this field worldwide, since more than 30 articles and research papers have been found related to the searching terms defined previously, and showing a wide diversity about implementation of circular economy in regions, cities, organizations, companies and products.

On the contrary, just 4 of these references are regulations, showing that the circular economy is just at the starting point from the point of view of directives, legislation and regulations.
Standardization and normalization activity related to circular and sustainable design is increasing, showing that 16 standards references have been found developed by normalization, standardization bodies and recognized organizations and institutions.

Some directives and regulations already exist related to sustainable design of packaging.

Next figure shows the distribution of the document type of the references that have been found.

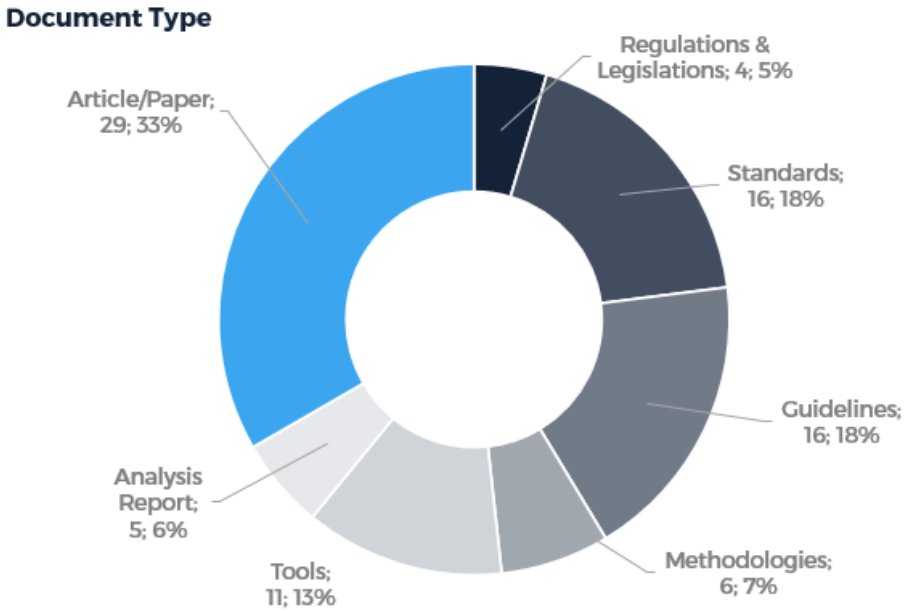


Figure 8. Type of Documents

Sections 7.2.7 to 7.2.9 shows an evaluation of the different standards, guidelines, methodologies, tools, reports, articles, research papers and other references.

7.2.2 Applicability Scope

General findings about application scope and certifiability of the references are described here.

Application Scope

Very diverse application scopes are found among all the references studied, analysing very different aspects related to the circular or sustainable design applicable to systems, services, products, components or materials.

Next figure shows the distribution of the different application scopes found, from system to material. Some of the references apply to different application scope levels, for example being applicable to product and component.

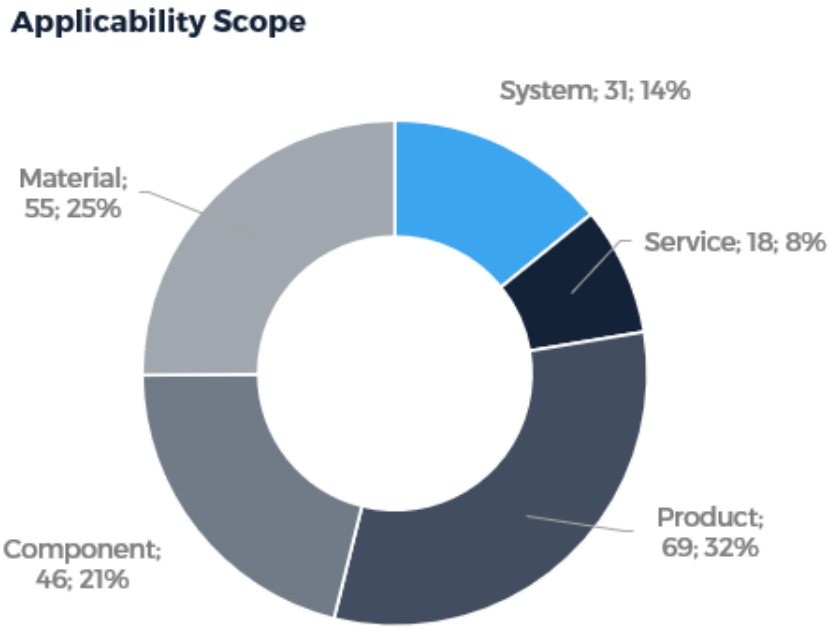


Figure 9. Application Scope

To point out very that are less references focused on a system or service level compared to product level.

The state of the art analysis has been focused on existing circular and sustainable design standards, guidelines, methodologies and tools focused on product, component or material level, considering that OW project is focused on EPS/XPS products and applications, usually used as a primary packaging.

Despite that, any comment or aspect found in references targeting system or services levels are extracted for the recommendations to be considered to that could be used to design circular and sustainable solutions for the EPS/XPS applications targeted in the project, explained in chapter 8.

Certifiability

Certifiability is analysed to know if a circular design of alternative EPS/XPS products and applications could be certified against any regulation, guideline or standard.

At the moment of performing this state of the art review process, just the regulations and standards listed in the following figure could be used as a reference to achieve a certification of products or components.

ID	Directive / Regulation /Standard	Developer	Document Type	Certifiability	Life Cycle Approach	Main Applicable Aspects to OW Project
5	ISO 14006:2011. Environmental management systems — Guidelines for incorporating ecodesign	ISO	STANDARD	Y	FULL	Ecodesign guidelines Can be integrated with other ISO standards
7	ISO 14025:2006. Environmental labels and declarations — Type III environmental declarations — Principles and procedures	ISO	STANDARD	Y	FULL	To be consider in OW project as a methodology to declare environmental impacts of a product
15	Cradle to Cradle Certified™ Product Standard V4.0	Cradle to Cradle Products Innovation Institute	STANDARD	Y	PARTIAL	- Material Health measurement - Product Circularity - Clean Air & Climate Protection - Water & Soil Stewardship - Social Fairness

Figure 10. Regulations & Standards and for certification of products

There are no standards and regulations to certify design of products, components or materials to improve social impacts.

Therefore, assuming that EPS/XPS products and applications can be considered mainly packaging products or components used to protect other products, these standards and guidelines are to be considered for a potential certification of EPS/XPS products and applications.

7.2.3 Design for X Approach

The design of a circular and sustainable product should consider all the applicable Design for X Approaches from the early stages of the design process, defined in section 7.1.3.

It was not found any reference defining how to design a circular and sustainable product including all the very specific and applicable "Design for X" approaches defined in section 7.1.3 in a structured way, and defining the different steps to follow within a design process of a specific product.

In general, not all "Design for X" approaches (level 2, level 3) are applicable to all products. The DfX approaches applicable to the design of a specific product will depend on the business model that is developed, the existing infrastructures along the value chain (waste management, recycling systems), the structure of the value chain and on the type of product (packaging, appliance, food product, machine, etc).

Next figure shows the distribution of the different design for X approaches considered among all the references studied. Some of the references can apply to different approaches.

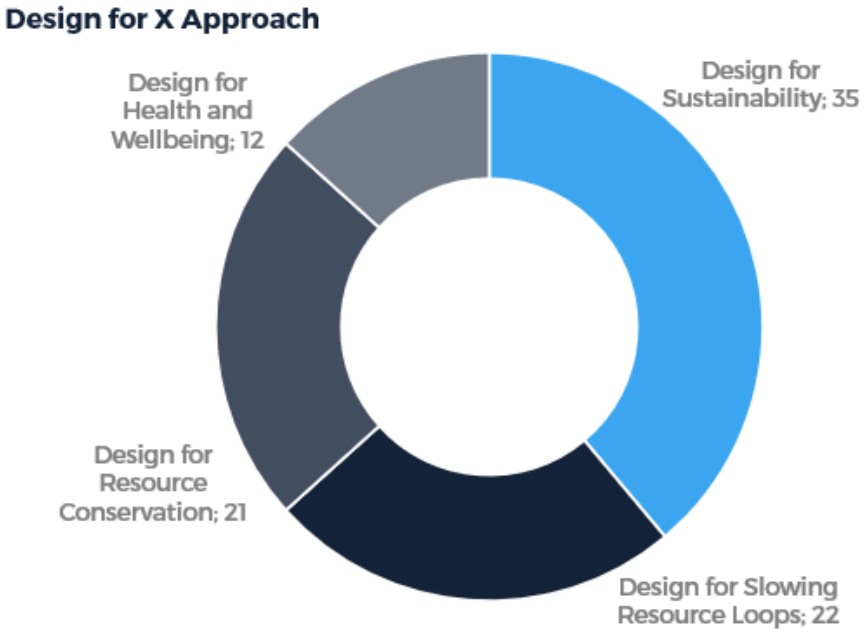


Figure 11. Design for X approaches summary

7.2.4 Life Cycle Approach

Then, life cycle approach is analysed. Designing a circular and sustainable product should take into account its complete life cycle considering all the life cycle phases described previously in section 7.1.4.

Some of the references analysed are considering the full life cycle approach, especially standards and recent methodologies for the design for circular economy. However, concept, design and definition phase is not considered.

Although designing a circular and sustainable product should be focused on its complete life cycle, references targeting one or several life cycle phases are also studied because they could mention relevant aspects in those specific phases that could be used for designing circular and sustainable alternatives to EPS/XPS products and applications.

7.2.5 Circularity

A circular and sustainable design of a generic product should consider, in principle, all the potential recirculations defined previously in sub-chapter 7.1.5 (repair, reutilization, remanufacture and recycle). Depending on the type of product, sector, value chain infrastructures, some of them could be more or less applicable.
Despite that, any mention to a specific of those aspects is compiled to take into account for designing circular and sustainable alternatives to EPS/XPS products and applications.

A homogeneous distribution of references related to repair, reutilization and remanufacture is found in the references. Remarkably, a higher number of references related to recycle is found.

Next figure shows the distribution of the different recirculations considered among all the references studied. Some of the references can apply to different recirculations.

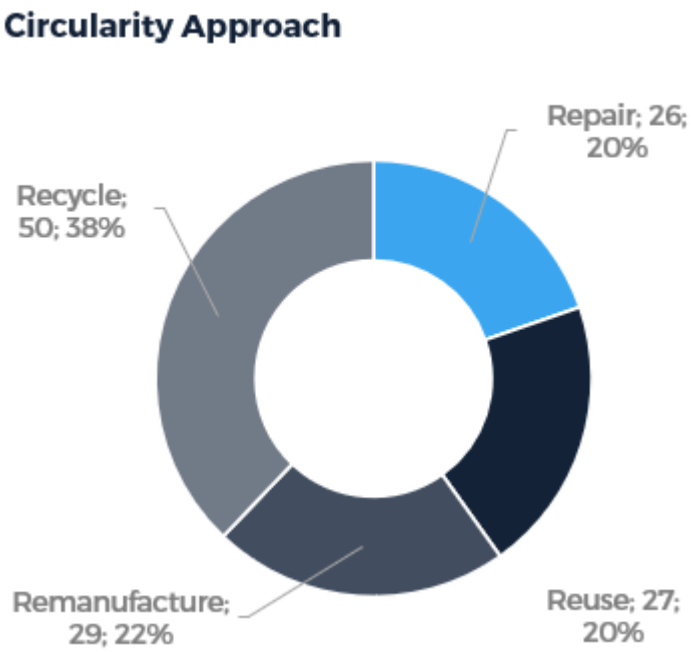


Figure 12. Circularity approach

7.2.6 Impacts Measurement Indexes

And finally, inclusion of indexes and indicators measuring environmental, economical and social impact is evaluated in all the references at micro and nano scale levels.

Summarizing, a lot of references address environmental impact of a particular aspect or life cycle phase using diverse specific metrics and indexes. On the contrary, cost or even life cycle cost and social impact analyses are very marginal.
Just the Orienting Project (see reference [17]) with the LCSA methodology is working on addressing an overall sustainability index, considering the 3 dimensions of sustainability, such as economics, environment and social, and integrating circularity principles.

Going through these steps, the *Circular & Sustainable Design References Database* for the assessment of the references found has been built. See Annex 10.1.

Following sections describe a detailed analysis of the most relevant references, focusing on the standards, guidelines, methodologies, tools and in the most relevant and applicable papers to OW project.

7.2.7 Directives, Regulations & Standards

A remarkable development of directives, regulations and standards related to concepts and practices for a circular and sustainable design has been carried out recently by standardization, normalization and recognized bodies.

European Directives and regulations related to packaging design to consider are:

- **Directive** (EU) 2018/851 amending Directive 2008/98/EC **on waste** (see reference [18]).
- **Directive** (EU) 2018/852 amending Directive 94/62/EC **on packaging and packaging waste** (see reference [19]).
- **REACH**, which is the European Regulation on Registration, Evaluation, Authorisation and Restriction of

Chemicals. It entered into force in 2007, replacing the former legislative framework for chemicals in the EU (see reference [20]).

Most relevant current international standards for designing sustainable packaging are:

- **ISO/TR 14062:2002** describes concepts and current practices relating to the integration of environmental aspects into product design and development (see reference [21]).
- **ISO 14006:2011** provides guidelines to assist organizations in establishing, documenting, implementing, maintaining and continually improving their management of ecodesign as part of an environmental management system (see reference [22]).
- **ISO 14044:2006** defines requirements and guidelines to perform a life cycle assessment of a product (see reference [23]).
- **ISO 14025:2006** establishes the principles and specifies the procedures for developing environmental product declarations type III, such as EPD (see reference [24]).
- **EN 13427 to EN 13432** standards (references [25] to [30]) define different kind of requirements for packaging related to sustainability and circularity:
  - EN 13427:2004, use of packaging and packaging waste
  - EN 13428:2004, manufacturing and composition, prevention.
  - EN 13429:2004, reuse.
  - EN 13430:2004, recovering by material recycling
  - EN 13431:2004, recovering by energy recovery
  - EN 13432:2001, recovering through composting and biodegradation
- **IEC 60300-3-3:2017**, establishes a general introduction to the concept of life cycle costing and covers all applications (see reference [16])
- **Cradle to Cradle Certified™ Product Standard V4.0**, from Cradle to Cradle Products Innovation Institute (see reference [31]), which defines guidelines for the design of a sustainable material or a product in these 5 categories:
  - Material Health – Chemicals and materials used in the product are selected to prioritize the protection of human health and the environment, generating a positive impact on the quality of materials available for future use and cycling.
  - Product Circularity – Products are intentionally designed for their next use and are actively cycled in their intended cycling pathway(s).
  - Clean Air & Climate Protection – Product manufacturing results in a positive impact on air quality, the renewable energy supply, and the balance of climate changing greenhouse gases.
  - Water & Soil Stewardship – Water and soil are treated as precious and shared resources. Watersheds and soil ecosystems are protected, and clean water and healthy soils are available to people and all other organisms.
  - Social Fairness – Companies are committed to upholding human rights and applying fair and equitable business practices.

Remarkably, The European Commission has presented on march 2022 a European Green Deal package of proposals to make sustainable products the norm in the EU, boost circular business models and empower consumers for the green transition.

This package contains the proposal for a **Regulation on Ecodesign for Sustainable Products** (see reference [32]) which addresses product design and establishes new requirements for products to be more durable, reliable, reusable, upgradable, repairable, easier to maintain, refurbish and recycle, energy and resource efficient. Final goal is to significantly improve product circularity, energy performance and other aspects of environmental sustainability.

This proposal will lead product manufacturers to integrate the following techniques into their product design and development processes to adapt their products to a carbon neutral future:

- Design for durability
- Design for disassembly
- Design for reuse
- Design for repair
- Design for renovation and remanufacturing
- Design for recycling
- Design for decarbonization

The following table shows most relevant aspects of these directives, legislation and standards related to circularity assessment and circular economy implementation, such as:

- Developer
- Certifiability
- Life cycle approach
- Main applicable aspects to OW project target

ID	Directive / Regulation / Standard	Developer	Document Type	Certifiability	Life Cycle Approach	Main Applicable Aspects to OW Project
1	DIRECTIVE (EU) 2018/851 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2008/98/EC on waste	European Commission	DIRECTIVE	N	PARTIAL	To be consider in the OW methodology as a requirement
2	DIRECTIVE (EU) 2018/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste	European Commission	DIRECTIVE	N	PARTIAL	To be consider in the OW methodology as a requirement
3	REACH	European Commission	REGULATION	Y	PARTIAL	Analitical method for chemical composition.
4	ISO/TR 14062:2002. Environmental management — Integrating environmental aspects into product design and development	ISO	STANDARD	N	PARTIAL	Environmental indicators for environmental design.
5	ISO 14006:2011. Environmental management systems — Guidelines for incorporating ecodesign	ISO	STANDARD	Y	FULL	Ecodesign guidelines Can be integrated with other ISO standards
6	ISO 14044:2006. Environmental management — Life cycle assessment — Requirements and guidelines	ISO	STANDARD	N	FULL	To be consider in the OW tool & methodology
7	ISO 14025:2006. Environmental labels and declarations — Type III environmental declarations — Principles and procedures	ISO	STANDARD	Y	FULL	To be consider in OW project as a methodology to declare environmental impacts of a product
8	EN 13427:2004. Packaging - Requirements for the use of European Standards in the field of packaging and packaging waste	EN	STANDARD	N	PARTIAL	To be consider in the OW methodology as a requirement
9	EN 13428:2004. Packaging - Requirements specific to manufacturing and composition - Prevention by source reduction	EN	STANDARD	N	PARTIAL	To be consider in the OW methodology as a requirement
10	EN 13429:2004. Packaging - Reuse	EN	STANDARD	N	PARTIAL	To be consider in the OW methodology as a requirement
11	EN 13430:2004. Packaging - Requirements for packaging recoverable by material recycling	EN	STANDARD	N	PARTIAL	To be consider in the OW methodology as a requirement
12	EN 13431:2004. Packaging - Requirements for packaging recoverable in the form of energy recovery, including specification of minimum inferior calorific value	EN	STANDARD	N	PARTIAL	To be consider in the OW methodology as a requirement
13	EN 13432:2001. Packaging - Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging	EN	STANDARD	N	PARTIAL	To be consider in the OW methodology as a requirement
14	IEC 60300-3-3:2017: Dependability management - Part 3-3: Application guide - Life cycle costing	Internacional Electrotechnical Comission	STANDARD	N	FULL	To be consider in the OW tool & methodology
15	Cradle to Cradle Certified™ Product Standard V4.0	Cradle to Cradle Products Innovation Institute	STANDARD	Y	PARTIAL	- Material Health measurement - Product Circularity - Clean Air & Climate Protection - Water & Soil Stewardship - Social Fairness
16	Proposal for Regulation on Ecodesign for Sustainable Products	European Commission	DIRECTIVE PROPOSAL	N	FULL	The framework to be developed in the next future should be considered for the development of alternative products and materials

Table 2. Circular & Sustainable Design Directives, Regulations & Standards

Main conclusions related to directives, regulations and standards are:

- It is compulsory to consider the current legislation with specific requirements for packaging (Directives 2018/851 and 2018/852).
- There are not standards & regulations defining how to design a complete circular and sustainable product.

In general, existing standards are not mentioning most of the Design for X approaches defined in section 7.1.3. Some of them are mentioning how to design for sustainability. However, the approval of the proposal for the Regulation on Ecodesign for Sustainable Products and its future transposition into regulations will be the reference for the design of sustainable products in Europe.

- It is difficult to find references with the triple impact vision. Most of the references are oriented to improve the environmental dimension and there aren´t references with a Global Circularity/Sustainability Index. There has been last years a remarkable development of standards related to life cycle assessment. Otherwise, no standards have been found yet to analyze the social impact of the life cycle of a product.
- For a sustainable and circular design of a packaging EN 13427 to EN 13432 standards are to be considered.
- Most of directives, regulations and standards oriented to a component or material oriented have a partial approach for the life cycle. Following standards are considering a full life cycle approach:
  - ISO 14006
  - ISO 14044
  - ISO 14025
  - IEC 60300-3-3
- Some recognized standards have been found about measuring impacts in life cycle, that might be incorporated to OW project circularity metodologies, indicators and tools, such as:
  - ISO 14044 defines requirements and guidelines to perform a life cycle assessment of a product (environmental impact)
  - ISO 26000 (reference [33]), applicable to business and organizations, could be used as a reference to include social aspects in the OW methodology. This standard defines a list of social issues to consider like human rights, health and safety, accessibility, etc.
  - IEC 60300-3-3:2017 should be considered to measure the life cycle cost
- It is worth noting Cradle to Cradle Certified™ Product Standard V4.0, which is one of the most complete standards nowadays to design a sustainable product considering the whole life cycle, which combines requirements related to material health, energy and water management, environmental impact assessment, circularity measurement and social impact of a product.

Additionally, it is important to note that the International Organization for Standardization (ISO) has been working since 2018 on the development of standards that help measure the circularity of organizations and products within the ISO/TC 323 Circular Economy technical committee. At the time of writing this report, the status is as follows.

The first drafts of the 59000 series standards on circular economy, resulting from the work developed by ISO/TC323, are in the voting phase. Its goal is the standardization in the field of Circular Economy to develop frameworks, requirements, guides, support tools for the implementation of activities of all the organizations involved, to maximize the contribution to Sustainable Development, being excluded from this committee the aspects of Circular Economy already covered by other existing committees.

These are the following drafts:

- **ISO59004: Circular Economy "Terminology, principles and guidance for implementation".** It is intended for private or public organizations, acting individually or collectively, regardless of their type or size, and located in any jurisdiction or position within a specific value chain or value network.
- **ISO59010: Circular Economy "Guidelines on the transition of business models and value networks".** It applies to any organization that deals with products or services, regardless of its size, sector or region.
- **ISO59020: Circular Economy "Measurement and evaluation of circularity".** Framework to be used to determine the effectiveness of circular actions carried out by public and private organizations. Its purpose is to assist organizations in collecting the necessary information to enable circular economic practices that minimize the use of resources and/or allow a circular flow of resources and contribute to sustainable development.

The goal of the future series of ISO59000 standards on Circular Economy is made up of a total of seven standards, as showed in the following figure.

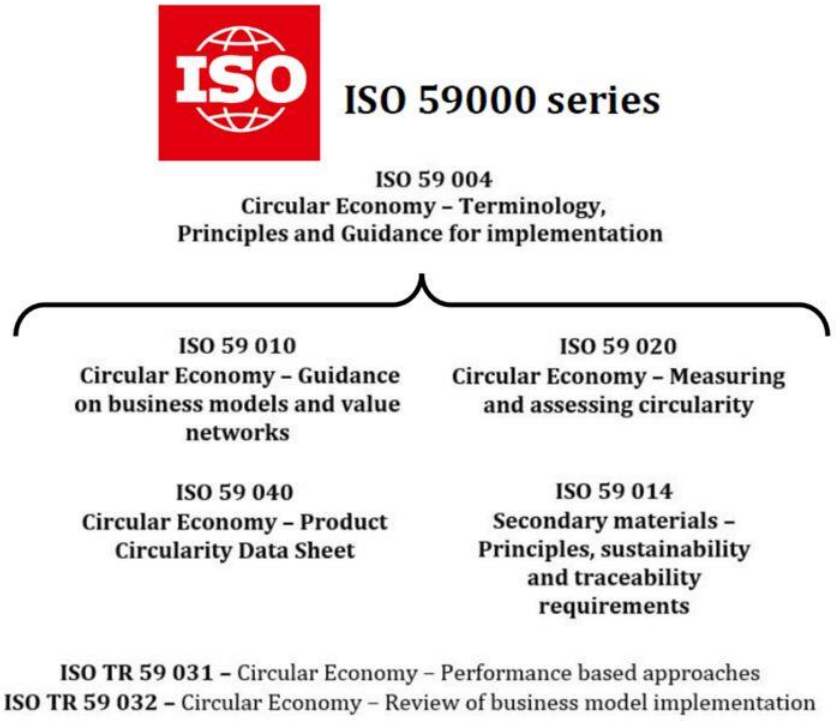


Figure 13. Future series of ISO 59000 standards on Circular Economy

This future ISO 59000 standards should be considered for the design of alternatives of EPS/XPS products and applications in combination to the aboved mentioned regulations and standards.

7.2.8 Guidelines, Methodologies and Tools

This section evaluates most relevant guidelines, methodologies and tools related to circular and sustainable design developed recently by recognized organizations of reference in sustainability and circular economy in the world and by private companies, working to promote and drive the transition to a circular economy and a more sustainable development.

Organizations, companies and projects contributing to the development of the most relevant guidelines, methodologies and tools, related to general products and packaging, are:

- Ellen Macarthur Foundation
- IHOBE, Sociedad Pública de Gestión Ambiental del País Vasco (Spain)
- Sustainable Packaging Coalition
- Biomimicry Institute
- Green Alliance
- Universities, such as TU Delft university and Washington University
- Private companies, such as:
  - Pré Sustainability
  - Intertek
  - ThinkStep
  - Autodesk

- Projects, such as:
  - RESCOM
  - Circular Design.it
  - ORIENTING
  - Packaging Cluster

The following table shows most relevant aspects of most recent and recognized methodologies, guidelines and tools related to circular and sustainable design, such as:

- Tool
- Developer
- Main applicable aspects to OW project target

ID	Guideline / Methodology / Tool	Developer	Document Type	Main Applicable Aspects to OW Project
1	Circular design toolkit	Ellen MacArthur Foundation	GUIDELINE	Main aspects: Circular design strategies, Smart material choices, Circular Design guide, Product journey mapping, Materials journey mapping Case studies, like Plastics: Reuse - Rethinking Packaging
2	Circular Design. Design for X Tool	Circular Design	GUIDELINE	It shows multiple references and case studies for a lot of Design for X approaches. Multiple life cycles approach. Consult library of publications
3	A definition of sustaintable packaging	Sustainable Packaging Coalition	GUIDELINE	Analyze sustainability strategies to apply to the different life cycle phases
4	The Slow Design Principles	TU Delft with Philips Research	GUIDELINE	Evaluate to consider to incorporate slow design process to OW project
5	The Principles of Universal Design	WASHINGTON UNIVERSITY	GUIDELINE	Universal design principles for ergonomy and use of packaging.
6	Sustainable Packaging Guidelines (SPGs)	APCO	METHODOLOGY	Design criteria according to 10 principles
7	Guide books on ecodesign. Containers and Packings	IHOBE	METHODOLOGY	Holistic and detailed analisis of strategies and examples.
8	The Recyclability Tool and guidelines for plastic package	RECYCLASS	GUIDELINE / METHODOLOGY / TOOL	Design-for-Recycling Guidelines & Certification Recyclability Rate Certification Recyclability analisis tool
9	The ResCoM platform and tools	RESCOM	TOOL	It brings together software applications and descriptive (i.e. non-software) tools and methods in one place to support decision-making and implementation of closed-loop product systems.
10	Instant LCA Packaging	Intertek	TOOL	Calculation tool on the total environmental impact using the Life Cycle Assessment for: Quantifying the environmental impact of packaging Improving the environmental performance by the eco-design approach
11	Circular Pack	Packaging Cluster / Inedit	GUIDELINE	It includes a matrix decision for the design of a packaging, a summary of ecodesign strategies to apply and analysis of circularity of different materials

Table 3. Circular & Sustainable Design Guidelines, Methodologies and Tools

The main conclusions of the evaluation of guidelines, methodologies and tools are:

- In general, guidelines, methodologies and tools found do not consider a full life cycle perspective. In particular, design and development phase of the life cycle is rarely considered.
- Usually, analysis of social impact and its measurement is not found within circular or sustainable design-related guidelines, methodologies and tools.
- All recirculations loops of products, components and materials (repair, reutilization, refurbishing, remanufacturing an recycling) are to be considered for a generic product. Even in this case, environmental impact is to be analyzed to make that the resulting product is to be sustainable. Products to be designed to contribute to a circular economy transition have to be sustainable.
- Related to the Design for X approaches, these are the most relevant guidelines and methodologies that could be applicable for the design of alternative EPS/XPS products and applications:
  - Guide books on ecodesign. Containers and Packaging: Methodology for ecodesign from preparation to action plan in the future applied to packaging and containers.
  - Circular design toolkit, it provides guidelines about circular design strategies, smart material choices, circular design guide, product journey mapping, materials journey mapping
  - Circular Design. Design for X Tool. It shows multiple references and case studies for a lot of Design for X approaches and a multiple life cycles approach.

- The Principles of Universal Design, guides about universal design principles for ergonomy and use of packaging.
- Sustainable Packaging Guidelines (SPGs), provides a design criteria according to 10 principles.
- Circular pack guidelines shows a summary of ecodesign strategies and recommendations for the design of a packaging focusing mainly on:
  - Reduction, optimization or elimination of packaging
  - Reuse
  - Materials recirculation

- Some of the most relevant design analysis tools for product and packaging found are:
  - Instant LCA Packaging: which allows to quantify the environmental impact of a packaging and helps improving the environmenal performance by the eco-design approach
  - RESCOM: The ResCoM platform brings together software applications and descriptive (i.e. non-software) tools and methods in one place to support decision-making and implementation of closed-loop product systems.
  - RECYCLASS: The Recyclability Tool for plastic package, regard to product recyclability, a label which you can license after successful certification in order to use it for marketing purposes in connection with the certified package. RecyClass published in 2021 the Design for Recycling Guidelines for EPS fish boxes and white goods, offering the plastic industry insights on how different components of EPS fish boxes and white goods packaging should be manufactured to be compatible with recycling. The RecyClass tool is a first step for EPS manufacturers to evaluate their packaging design, prior to the issuance of a recyclability certification of the EPS packaging attesting to the fact that it is fully recyclable and sustainable.
- Remarkably, the H2020 project "ORIENTING" (reference [17]), running at the time of writing this report, is aiming to a robust, comprehensive, and operational methodology for LCSA of products (goods and services) to support the transition towards a circular economy. Life cycle sustainability assessment (LCSA) refers to the evaluation of all environmental, social and economic negative impacts and benefits in decision-making processes towards the development of more sustainable products throughout their life cycle. According to this framework, the methodology consists of an approach combining environmental LCA, social LCA and life cycle costing (LCSA = LCA + S-LCA + LCC). In addition to the three pillars addressed in the original LCSA framework, the ORIENTING LCSA methodology also includes indicators and methods that enable a coherent and practical assessment of product circularity and raw material criticality in the context of an LCSA study

7.2.9 Reports, Articles, Papers and other References

There has been found a great analysis and research activity in the field of circular and sustainable design. This analysis and research activity is oriented mainly to the following 3 different areas:

- General sustainable product design
- Different design for X approaches (design for repair, design for circularity, design for lifetime, etc)
- Sustainable Packaging design

The following table shows the most relevant analysis reports, articles, papers and other references related to circular and sustainable design methdologies and techniques of general products and packaging in particular.

- Developer
- Purpose
- Main applicable aspects to OW project target

ID	Article / Paper	Developer	Purpose	Main Applicable Aspects to OW Project
1	A Conceptual Framework for Circular Design	Mariale Moreno, Carolina De los Rios, Zoe Rowe and Fiona Charnley	DESIGN FOR CIRCULARITY	A very complete framework of the different design for X approaches to consider when designing a circular and sustainable product or component, giving numerous references about them.
2	Sustainable packaging design: A holistic methodology for packaging design	John Wiley & Sons, Ltd.	SUSTAINABLE PRODUCT DESIGN	This document contains a number of indicators that are grouped into categories evaluating packaging in the whole distribution chain, from manufacturer to end consumer and the life cycle. This mathodology could be applied in Ocean wise project.
3	Design for manufacture and design for 'X': Concepts, applications, and perspectives	Tsai Chi Kuo, Samuel Huang, Hong-Chao Zhang	DESIGN FOR MANUFACTURING	To take into account if we include the "design for manufacturing" perspective
4	Circular Product Design. A Multiple Loops Life Cycle Design Approach for the Circular Economy	Ana Mestre & Tim Cooper	SUSTAINABLE PRODUCT DESIGN	Indicators and diagram analisis that could be applied on Ocean Wise design analiss of current and alternatives EPS/XPS solutions
5	Circular economy – From review of theories and practices to development of implementation tools	Yuliya Kalmykova, Madumita Sadagopan, LeonardoRosa	SUSTAINABLE PRODUCT DESIGN	This document have 45 CE strategies that are applicable to different parts of the value chain.
6	Realizing Product-Packaging Combinations in Circular Systems: Shaping the Research Agenda	Bjorn de Koeijer - Renee Wever and Jörg Henseler	PACKAGING	Includes eight relevant diagram-type models and tools from three backgrounds: packaging development,sustainable development and sustainable packaging development
7	A Compilation of Design for Environment Guidelines	Cassandra Telenko	SUSTAINABLE PRODUCT DESIGN	Evaluaction of tools and methodology for circular product design with application on Ocean Wise.
8	BECE FRAMEWORK	Journal of Industrial Ecology Special Issue (Exploring The Circular Econony)	DESIGN FOR CIRCULARITY	Consider eco-design approaches
9	Use of Bio-Based Plastics in the Fruit Supply Chain: An Integrated Approach to Assess Environmental, Economic, and Social Sustainability	Simone Blanc, Stefano Massaglia, Filippo Brun, Cristiana Peano, Angela Mosso and Nicole Roberta Giuggioli	DESIGN FOR LIFETIME EXTENSION	Methodological framework for identifying and quantifying the environmental, economic, and social impacts related to the use of plastics in the agro-food chain could be directly applied in Ocean Wise.
10	Eco-Efficiency Assessment of Bioplastics Production Systems and End-of-Life Options	Kunnika Changwichan, Thapat Silalertruksa and Shabbir H. Gheewala	PACKAGING (BIO BASED)	Analyze way of evaluating environmental and economic sustainability of bioplastics production together with end-of-life (EOL) options
11	Addressing circular economy through design for X approaches: A systematic literature review	Claudio Sassanellia Andrea Urbinatia Paolo Rosa	DESIGN FOR X APPROACHES LITERATURE REVIEW	A complete literature review about design for X approaches to consider when designing a circular and sustainable product or component, giving numerous references about them.

Table 4. Extract of main Circular & Sustainable Design Analysis Reports, Articles, Papers and other References

The main conclusions of the evaluation of analysis reports, articles, papers and other references are:

- The article "A Conceptual Framework for Circular Design" (see reference [34]) shows a very complete framework of the different design for X approaches to consider when designing a circular and sustainable product or component, giving numerous references about them. More papers giving a literature review about design for x approaches can be found, such as the corresponding to reference 11 in the previous table.
- In general, most of references do not consider a full life cycle perspective. In most cases, references are focused on an specific life cycle phase or specific indicator
- It's difficult to find an article or a paper defining how to integrate social impact within the design process of a product.
- Indicators related to assess environmental, cost and social performance and impacts should be considered when designing a particular product. In this matter, project ORIENTING (reference [17]) has carried out recently a complete and comprehensive review of the state of the art of the following specific aspects and the combination of them to perform integrated sustainability and circularity assessments:
  - LCA and environmental approaches
  - LCC and economic approaches
  - S-LCA and social evaluation approaches
  - LCSA approaches
  - Materials criticality
  - Product circularity assessment
- Related to the Design for X approaches, these are the most relevant articles and papers (most of them focused on packaging) that could be applicable for the design of alternative EPS/XPS products and applications:
  - Sustainable packaging design: A holistic methodology for packaging design. It is focused on strategies and indicators for sustainable packaging design.
  - Design for manufacture and design for 'X': Concepts, applications, and perspectives: The objective of this paper is to present the concepts, applications, and perspectives of 'DFX' in manufacturing, thus providing some guidelines and references for future research and implementation.

- Holistic View of the Role of Flexible Packaging in a Sustainable World strives to provide a comprehensive view on flexible packaging and its environmental impacts.
- Realizing Product-Packaging Combinations in Circular Systems: Shaping the Research Agenda
- A Compilation of Design for Environment Guidelines
- BECE FRAMEWORK
- Use of Bio-Based Plastics in the Fruit Supply Chain: An Integrated Approach to Assess Environmental, Economic, and Social Sustainability
- Eco-Efficiency Assessment of Bioplastics Production Systems and End-of-Life Options

7.3 CONCLUSIONS

This chapter shows the main conclusions extracted from state of the art review analysis of circularity assessment references described in the previous chapters.

A great effort has been detected in the recent years about how to design circular and sustainable products, defining methodologies and developing tools about specific issues related to designing for sustainability and for circularity.

As a general conclusion, no methodology or reference developed adhoc for EPS/XPS has been found at this moment that could be fully and directly applied to design circular and sustainable alternative EPS/XPS products and applications in a structured way, considering the different potential types of application. However, a lot of relevant aspects can be used to develop an specific methodology and tools to perform it. See the details and recommendations for OW project in chapter 8.

First of all, a brief summary of the analysis overview is given, following the analysis criteria described in chapter 7.1.

- **Document type**

Regarding the type of document analysed, to point out that some regulations or legislations already exist related to design circular or sustainable materials or products.
There is great research activity in this field (more than 30 articles and papers found) and a remarkable effort is being done around the world to develop standards, guidelines and methodologies to design circular and sustainable products.

- **Applicability scope**

Very diverse application scopes are found among all the references studied, analysing very different aspects related to the circular or sustainable design applicable to systems, services, products, components or materials. To point out that very few references are focused on a system or service level.

Regarding certifiability, just the following standards can be used to certify a product related to sustainable design:

- ISO 14006
- ISO 14025
- Cradle to Cradle Certified™ Product Standard

- **Design for X approach**

There are a lot of references related to different design for X approaches, as defined in section 7.1.3. It was not found any reference defining how to design a circular and sustainable product including all the specific and applicable "Design for X" approaches in a structured way.

- **Life cycle approach**

Some of the references analysed are considering the full life cycle approach, especially standards and recent methodologies for the design for circular economy. However, concept, design and definition phase is not considered.

- **Circularity**

A homogeneous distribution of references related to repair, reutilization and remanufacture is found in the references. Remarkably, a higher number of references related to recycle is found. Recent guidelines and proposals for regulation are introducing the need of considering all the potential recirculations of the product, its components and materials from the design phase.

- **Impacts Measurement Indexes**

A lot of references address environmental impact of a particular aspect or life cycle phase using diverse specific metrics and indexes. On the contrary, cost or even life cycle cost and social impact analyses are very marginal.

Few of the references found defines how to calculate an overall index to measure the sustainability and circularity of alternative solutions for a particular product, considering the 3 dimensions of sustainability, such as economics, environment and social.

Summarizing, main conclusions extracted from the detail analysis of regulations, standards, guidelines, methodologies, tools, reports, articles and papers are presented:

- Although it is compulsory to consider the current legislation with specific requirements for packaging (Directives 2018/851 and 2018/852), there are no binding regulations for the design a circular and sustainable product. Future Regulation on Ecodesign for Sustainable Products and its future transposition into regulations will be the reference for the design of sustainable products in Europe.
- Regarding standards:
  - some of them define requirements for packaging related to sustainbility and circularity (from EN13427 to EN 13432)
  - in general, existing standards are neither mentioning most of the Design for X approaches identified in this document (see section 7.1.3) nor defining in a structured way how to design a sustainable and circular product depending on the different type of application
  - although there are generic standards considering a full life cycle approach and focused on analysing environmental impact from the design phases (ISO14006, ISO14025, ISO14044), no standards consider a triple impact vision (environmental, economic, social) nor the calculation of a overall circularity/sustainability index to estimate how sustainable and circular a product is going to be
  - Cradle to Cradle product standard is a reference to follow to design a sustainable product, which considers the whole life cycle and combines requirements related to material health, energy and water management, environmental impact assessment, circularity measurement and social impact of a product.
  - future ISO 59000 standards will standardize how to consider and evaluate circularity principles when designing products and business models
- A relevant number of guidelines, methodologies and tools to design a product oriented to sustainability have been found. These are the main aspects to consider:
  - Usually analysis of social impact and its measurement is not addressed
  - All recirculations loops of products, components and materials (repair, reutilization, refurbishing, remanufacturing an recycling) are to be considered for a generic product. Even in this case, environmental impact is to be analyzed to make that the resulting product is to be sustainable.

- Main references specifically refers to ecodesign and design for recycling, but not defining how to consider the DfX (Design for X) approaches in a structured way depending on the type of product or potential applications.
- Most relevant references to consider for the design of alternative EPS/XPS products and applications are:
  - Design for Recycling Guidelines for EPS fish boxes and white goods, from Recyclass
  - Sustainable Packaging Guidelines (SPGs), which provides a design criteria according to 10 principles
  - Circular pack guidelines, which shows a summary of ecodesign strategis and recommendations for the design of a packaging
- A future comprehensive and operational methodology based on LCSA approach, derived from ORIENTING project, will define how to combine environmental LCA, social LCA and life cycle costing, and integrating assessment of product circularity in order to assess sustainability and circularity of a product with an overall sustainability/circularity index.

- Regarding papers and other relevant articles and references, there is a remarkable recent research activity about different methodologies related to circular design, design for sustainablity, design for X approaches in general, and for packaging design specifically. In particular, article "A Conceptual Framework for Circular Design" (reference [34]) defines a very complete framework of different design for X approaches applicable to design a circular and sustainable product.

8 RECOMMENDATIONS TO DESIGN CIRCULAR AND SUSTAINABLE SOLUTIONS FOR EPS/XPS PRODUCTS

This chapter includes the recommendations, resulting from this state of the art analysis, to design circular and sustainable alternative technical solutions for EPS/XPS products and applications.

The main 3 principles of Circular Economy, as defined previously in section 7.1.3, have to be considered when designing circular and sustainable generic products and, specifically, alternative EPS/XPS products and applications. These principles are:

- **Principle 1**: Preserve and enhance natural capital by controlling finite stocks and balancing resource flows, meaning that technology and processes are chosen wisely according to their use of renewable or better-performing resources.
- **Principle 2**: Optimize resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles; meaning designing for remanufacturing, refurbishing and recycling to keep technical components and materials circulating in the economy, preserving embedded energy and other value. It also refers to encouraging biological nutrients to re-enter the biosphere in the safest way possible to become valuable feedstock for a new cycle.
- **Principle 3**: Foster system effectiveness by revealing and designing out negative externalities; this includes reducing damage to human utility, such as food, mobility, shelter, education, health and entertainment, and managing externalities, such as land use, air, water and noise pollution, release of toxic substances and climate change.

These principles are to be translated into specific design for X methodologies and tools, that should be integrated within the design process of a product from its conceptual design phase.
These design for X approaches to consider when designing a generic product, are briefly listed in 7.1.3, described in 10.2 and showed again in the next figure.

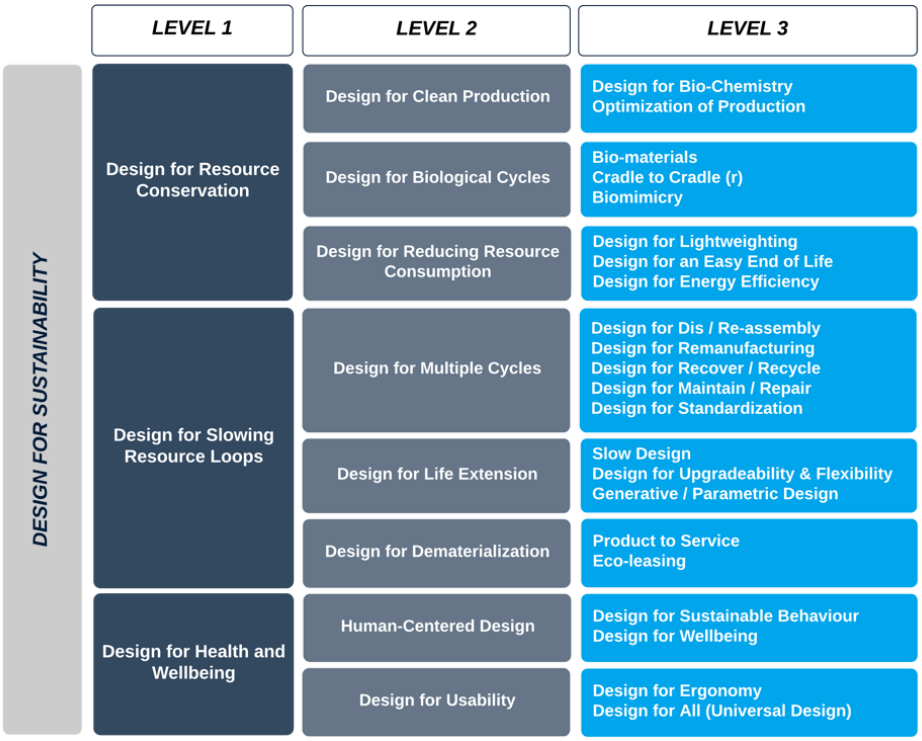


Figure 14. Design for X approaches summary

The specific applicable design for X approaches to consider when designing generic products, depend on the business model related (B2B, B2C), the type of application targeted (final consumer packaging, intermediate packaging, etc), the particularities of the product and the existing infrastructures and systems along the value chain (waste management, recycling, reverse logistics, remanufacturing, etc), among other requirements. In any case, the applicable design for X approaches and methodologies have to be structured in a specific methodology aiming to obtain an optimal technical solution in terms of sustainability (environmental impact, costs, social impact) and circularity.

Moreover, a key aspect to consider when designing an optimal sustainable generic product, or EPS/XPS alternative, is to ensure that a sustainability and circularity assessment for the design alternatives under study is to be carried out from the conceptual design phases of the product. In this regard, as identified in WP6.1 deliverable (reference [35]), LCSA (Life Cycle Sustainability Assessment) approach should be considered at the end of conceptual design phase, to combine environmental impact (LCA, Life Cycle Analysis), cost impact (LCC, Life Cycle Cost) and social impact (SLCA, Social Life Cycle Analysis) assessments, integrating circularity evaluation.

The following picture shows the typical workflow of a conceptual design phase of a generic product.

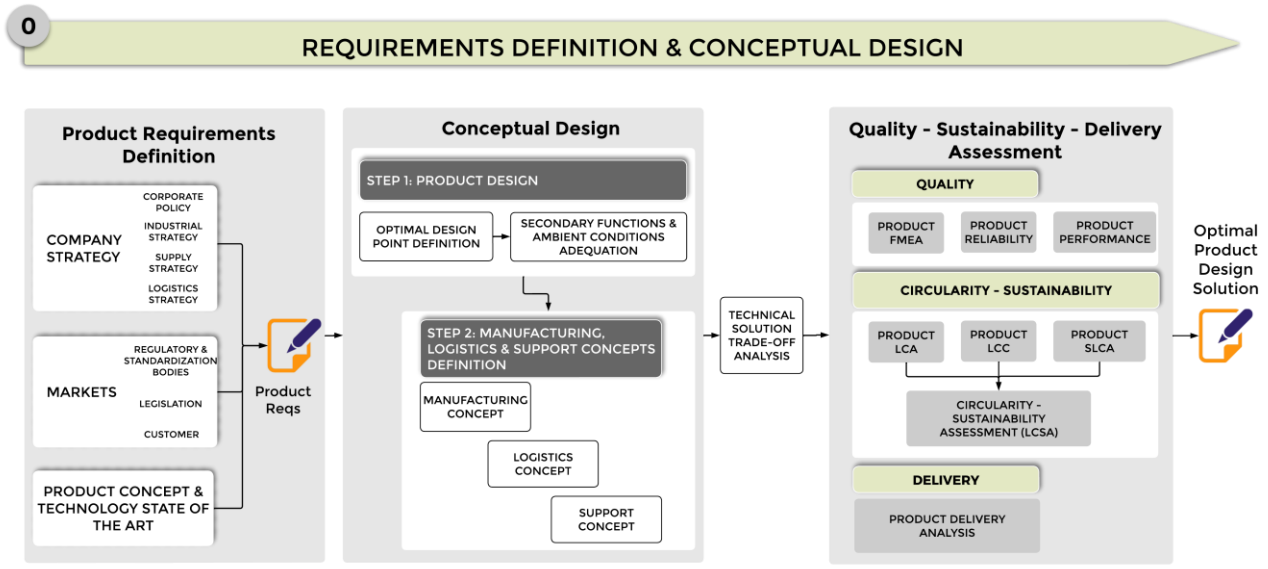


Figure 15. Conceptual Design Phase Overview

First group of activities when designing a sustainable product refer to the definition of the product requirements. At this point, all the sustainability and circularity requirements are to be defined collecting requirements from the company strategy, the market (regulations, standards, certifications, customer, etc) and the state of the art (manufacturing technologies, materials, infrastructures along the value chain, end of life systems, etc).

After defining product requirements, product design activities start aiming to obtain an optimal design solution (Step 1). Then, once main parameters of the product are defined, manufacturability and supportability design assessments are to be carried out in order to define manufacturing concept, logistics and support (if applies) concepts (Step 2).

For EPS/XPS products and applications, focusing on a packaging application, the following Design for X approaches should be typically considered within the Step 1 (Product Design activities), considering the alignment to Circular Economy Principles and to the future Regulation on Ecodesign for Sustainable Products:

- Design for efficiency on the materials and resources use all along the whole life cycle
- Design for recycled contents, to incorporate recycled materials
- Design for multiple cycles, mainly:
  - Design for recovery
  - Design for reuse
  - Design for recycling
  - Design for biological cycles
- Design for decarbonization (minimising carbon emissions) and Design for reducing the environmental impacts throughout the whole life cycle
- Design for accessibility (design 4 All)

Applicability of these techniques will depend, in each EPS/XPS application case, on the type of business model (B2B, B2C), the type of application targeted (final consumer packaging, intermediate packaging, etc), the material chosen (technical, biological) and the existing infrastructures throughout the value chain (reverse logistics, waste management, recycling systems) in the target market.

Finally, to ensure that the technical solution trade off analysis is done to obtain the optimal technical solution in terms of circularity and sustainability, a circularity-sustainability assessment of the design alternatives is to be done within the group of activities related to the quality – sustainability – delivery assessment. This is where a specific methodology for the circularity – sustainability assessment of the product should be used, based on the LCSA approach, as mentioned above. Deliverable 3 of Oceanwise WP6 (reference [36]) develops a methodology to perform a circularity – sustainability assessment of EPS/XPS products and applications.

9 REFERENCES

[1] What is the circular economy? Ellen Macarthur Foundation (https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy)
[2] European Commission - Press release. Closing the loop: Commission adopts ambitious new Circular Economy Package to boost competitiveness, create jobs and generate sustainable growth (http://europa.eu/rapid/press-release_IP-15-6203_en.htm)
[3] Plastic Waste: a European strategy to protect the planet, defend our citizens and empower our industries. European Commission. 16/01/18 (http://europa.eu/rapid/press-release_IP-18-5_en.htm)
[4] Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions on making sustainable products the norm. European Commission. March 2022 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0140&qid=1649112555090)
[5] A European Green Deal. Striving to be the first climate-neutral continent. European Commission. Dec 2019 (https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en)
[6] Circular economy action plan. European Commission. March 2020 (https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en)
[7] Oceanwise project website (http://www.oceanwise-project.eu/)
[8] Scopus database. Elsevier. (https://www.scopus.com/)
[9] Researchgate (https://www.researchgate.net/)
[10] ScienceDirect (https://www.sciencedirect.com/)
[11] Web of Science (https://clarivate.com/products/web-of-science/)
[12] Wiley online library (https://onlinelibrary.wiley.com/)
[13] MDPI Multidisciplinary Digital Publishing Institute (https://www.mdpi.com/)
[14] Circular & Sustainable Design References Database (CircularityModelsReferencesDB_R0.xlsx)
[15] ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework. Second Edition 2006
[16] IEC 60300-3-3 2017: Dependability management. Application guide – Life cycle costing
[17] Orienting Project (http://www.orienting.eu/)
[18] DIRECTIVE (EU) 2018/851 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2008/98/EC on waste.
[19] DIRECTIVE (EU) 2018/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste.
[20] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).
[21] ISO/TR 14062: Environmental management — Integrating environmental aspects into product design and development. First Edition 2002
[22] ISO 14006: Environmental management systems — Guidelines for incorporating ecodesign. Edition 2020
[23] ISO 14044: Environmental management — Life cycle assessment — Requirements and guidelines. First Edition 2006
[24] ISO 14025. Environmental labels and declarations — Type III environmental declarations — Principles and procedures. Edition 2006
[25] EN 13427:2004. Packaging - Requirements for the use of European Standards in the field of packaging and packaging waste
[26] EN 13428:2004. Packaging - Requirements specific to manufacturing and composition - Prevention by source reduction
[27] EN 13429:2004. Packaging - Reuse
[28] EN 13430:2004. Packaging - Requirements for packaging recoverable by material recycling
[29] EN 13431:2004. Packaging - Requirements for packaging recoverable in the form of energy recovery, including specification of minimum inferior calorific value
[30] EN 13432:2001. Packaging - Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging

[31] Cradle to Cradle Certified™ Product Standard. 2021. Version 4. Cradle to Cradle Products Innovation Institute
[32] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS On making sustainable products the norm. March 2022
[33] ISO 26000: Guidance on social responsibility. First Edition 2010
[34] A Conceptual Framework for Circular Design. Centre for Competitive Creative Design (C4D). MDPI. Mariale Moreno, Carolina De los Rios, Zoe Rowe and Fiona Charnley. 2016
[35] Work Package 6. Activity 1. State of the Art Report on Circularity Assessment Methodologies. Sustainn. 2022
[36] Work Package 6. Activity 3. Methodology for the Circularity Assessment of EPS/XPS Products and Applications. Sustainn. 2022

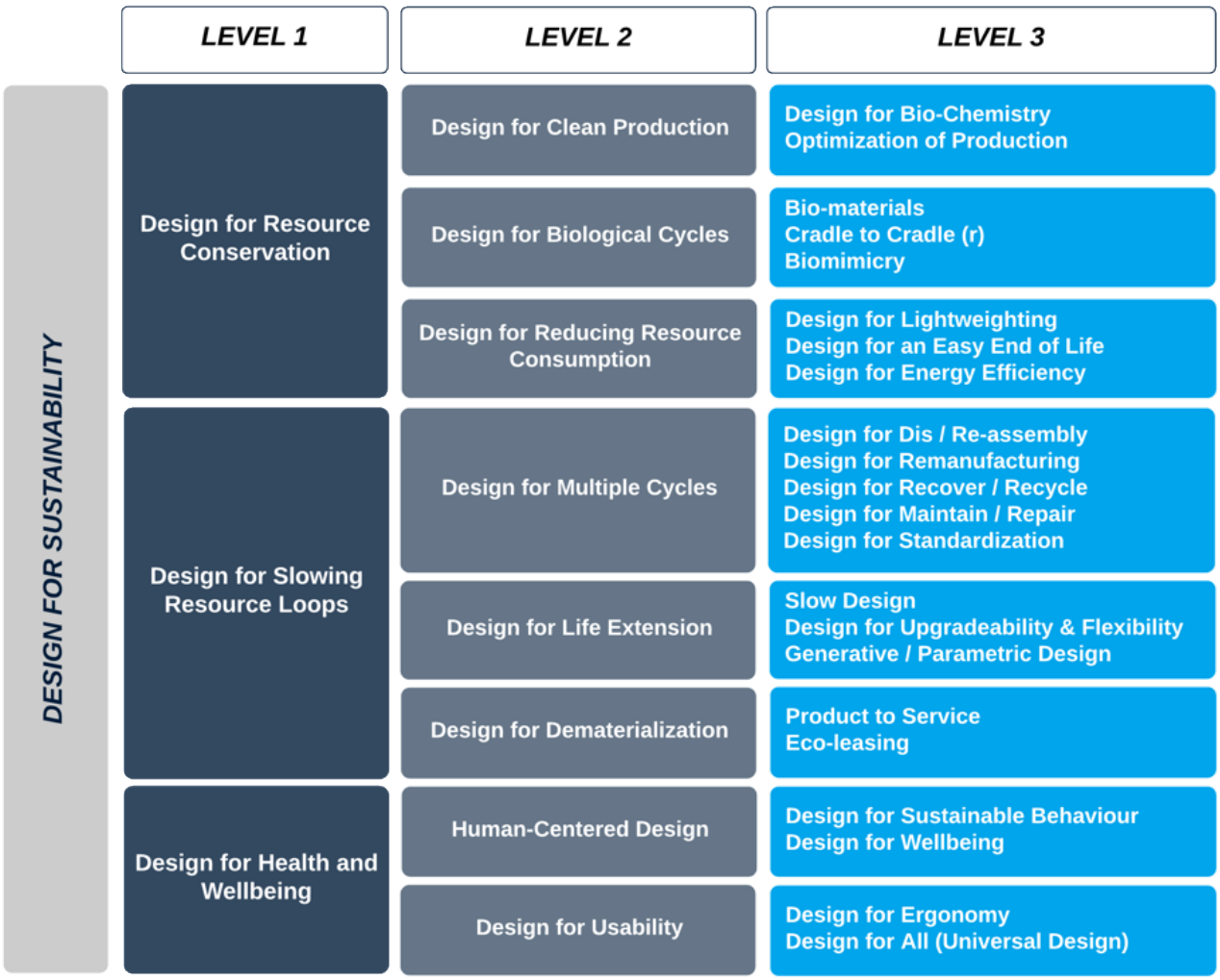
10 ANNEXES

10.1 ANNEX 1: CIRCULAR & SUSTAINABLE DESIGN REFERENCES DATABASE

CircularityModelsReferencesDB_R0.xlsx

10.2 ANNEX 2: DESCRIPTION OF DESIGN FOR X APPROACHES

This annex includes a brief description of the different "Design for X" approaches (Level 2 and Level 3), as defined in section 7.1.3 and summarized in Figure 7.



Design for Resource Conservation

- Green chemistry (Bio-chemistry). Green chemistry is the utilisation of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products.

- Optimization of production techniques. Cleaner production is the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase eco-effi ciency and reduce risks for humans and the environment.

- Bio-materials. A biomaterial is any substance that has been engineered to interact with biological systems for a medical purpose - either a therapeutic (treat, augment, repair or replace a tissue function of the body) or a diagnostic one.

- Cradle to cradle. C2C suggests that industry must protect and enrich ecosystems and nature's biological metabolism while also maintaining a safe, productive technical metabolism for the high-quality use and circulation of organic and technical nutrients.

- Biomimicry. Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature’s time-tested patterns and strategies

- Design for lightweight / material reduction. This method focuses on lightweighting design from the design phase and manufacturing lightweight to ligthwieght materials.

- Design for easy end-of-life. This strategy focus on facilitate cleaning, collection and transportation of recovered materials/ resources.

- Energy efficiency. Energy efficient design focuses on developing products that use energy significantly less than a standard or traditional version of that product. Energy efficient is becoming increasingly popular not only because of the cost savings associated with constantly rising energy prices but also because of reduced environmental impact.

- Design for bio-chemistry. Biological chemistry, is the study of chemical processes within and relating to living organisms.

Design for Slowing Resource Loops

- Design for dissasembly / remanufacture. Design for Disassembly is a design strategy that considers the future need to disassemble a product for repair, refurbish or recycle.

- Design for recover / recycle. Design for recycling targets the same features as design for disassembly. It addresses more specifically the selection of materials and sets their recycling rate. It further points out the need to form recycled materials into new products.

- Design for maintain / repair. Design for maintain / repair is a strategy focused on maintaing / repairing products for his life extensión and durability.

- Design for standarization. Design for standardization approach depends heavily on how successful designers are at implementing and using the current available set of parts and reusing them for creating new products by minimizing total number of parts used.

- Slow design. It is a design philosophy that aims at supporting people in doing things at the right time and the right speed, in order to give them time to understand and reflect about their actions. Slow Design

Products are designed to support social, cultural and environmental.

- Design for upgradability. Product upgradability aims to replace only those components that devalue over time. enhancing functions of the product, lowering price and environmental load, and increasing profitability for manufacturers

- Generative design. Generative design is used to describe a variety of new CAD tools which are all engineered to optimize manufacturability, lightweight products and save on material usage.

- Design for modularity. Design for modularity is an approach that subdivides a system into smaller parts called modules or skids, that can be independently created and then used in different systems.

- Product to service. Product as a service is a transaction of service production and delivery model in which a productized service is sold by the seller or vendor to the buyer and is centrally hosted, either on a standalone website or an open marketplace platform.

- Eco-leasing. Ecoleasing is a system in which goods (mainly from the technical cycle, i.e. appliances, ...) are rented to a client for a certain period of time after which he returns the goods so the company that made it can recycle the materials.

Design for Health and Wellbeing

- Design for sustainable behavior. Design for Sustainable Behaviour (DfSB) is an emerging activity under the banner of sustainable design which aims to reduce products environmental and social impact by moderating how users interact with them.

- Design for wellbeing. Design for wellbeing is a method using healthy materials and products that make feel better during the use of the products/ service.

- Design for ergonomy. Design for ergonomy is a strategy that understand how objects and human bodies interact in a physical way efficiently.

- Universal design. Universal Design is the design and composition of an environment (product, buiiding, service) so that it can be accessed, understood and used to the greatest extent possible by all people regardless of their age, size, ability or disability.