OCEAN WISE

Reducing EPS marine litter in the North East Atlantic

# Work Package 6. Activity 1

# State of the Art Report on Circularity Assessment Methodologies

sustainn

Interreg Atlantic Area

European Regional Development Fund

EUROPEAN UNION

## INDEX



## CHANGES RECORD

| Rev. | Date | Author | Description |
|---|---|---|---|
| Draft 0 | 24/05/19 | Sustainn | Initial Version |
| Draft 1 | 25/05/20 | Sustainn | 2020 Update |
| Draft 2 | 16/08/21 | Sustainn | 2021 Update |
| 0 | 31/08/22 | Sustainn | 2022 Update and Final Version |

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## 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 perform circularity assessment for generic products, and gives recommendations to perform a circularity assessment of alternative solutions for 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 have been detected in the recent years on analysing how the circular economy principles are being implemented in regions, cities, organizations and products, studying the different literature about how to perform a circularity assessment of organizations and products.

There is great research activity in this field (more than 50 articles and papers found) and a remarkable effort is being done around the world to develop standards, guidelines and methodologies to assess circularity of territories, cities, organizations, products and components.

No specific regulations to perform circularity assessments of products have been developed yet. It evaluates the most relevant standards, guidelines or methodologies developed by normalization, standardization bodies and recognized organizations and institutions, showing that the circular economy is just at the starting point from the point of view of the legislation and regulations.

As a general conclusion, no methodology or reference developed adhoc for EPS/XPS has been found at this moment to carry out a circularity assessment of EPS/XPS products and applications. However, a lot of relevant aspects can be used to develop an specific methodology and tools to perform it combining circularity and sustainability assessments.

Finally, this report provides recommendations to the development of a methodology to perform circularity and sustainability assessment of alternative technical solutions for EPS/XPS products and applications, which is to be developed in activity 3 of the work package 6 of OW project.

As a general approach, circularity assessment of the life cycle of a product should be aligned to circular economy principles, that are:

- Principle 1: Design out waste and pollution
- Principle 2: Keep products and materials in use
- Principle 3: Regenerate natural systems

Circularity has to be sustainable. So then, the 3 dimensions of sustainability (economical, environmental and social) should be considered to analyze circularity and sustainability integrated. LCSA (Life Cycle Sustainability Assessment) approach should be the main reference to follow, combining environmental impact (LCA, Life Cycle Analysis), cost impact (LCC, Life Cycle Cost) and social impact (SLCA, Social Impact Life Cycle Analysis) assessments.

Furthermore, different aspects are to be considered to integrate circularity assessment together with the environmental, cost and social impacts of the alternative solutions for the targeted EPS/XPS products and applications in OW project.

# 1 AIM

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 perform circularity assessment for generic products, and specifically for EPS/XPS products and applications.

Furthermore, this report gives recommendations to **OceanWise** Project to perform circularity assessment of current EPS/XPS applications and sustainable alternatives to be analyzed throughout the project.

This document corresponds to the resulting deliverable from **action 6.1 of WP6** (Circularity Indicators and Tools) of **Oceanwise project**, that is *Review of Circularity Indicators/Tools to help evaluate 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, life cycle approach, circularity orientation and impacts measurement.

This chapter gathers and evaluates the different references (regulations, standards,methodologies, and tools) found to perform a circularity assessment for generic products, and specifically for EPS/XPS products and applications, paying attention to the status of regulations, standards and guidelines and other general reports and articles. 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

Finally, the report concludes by providing recommendations in *Chapter 8* to perform circularity assessment of the EPS/XPS applications targeted in the project.

Annex 1 includes the *Circularity Assessment 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].

***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.

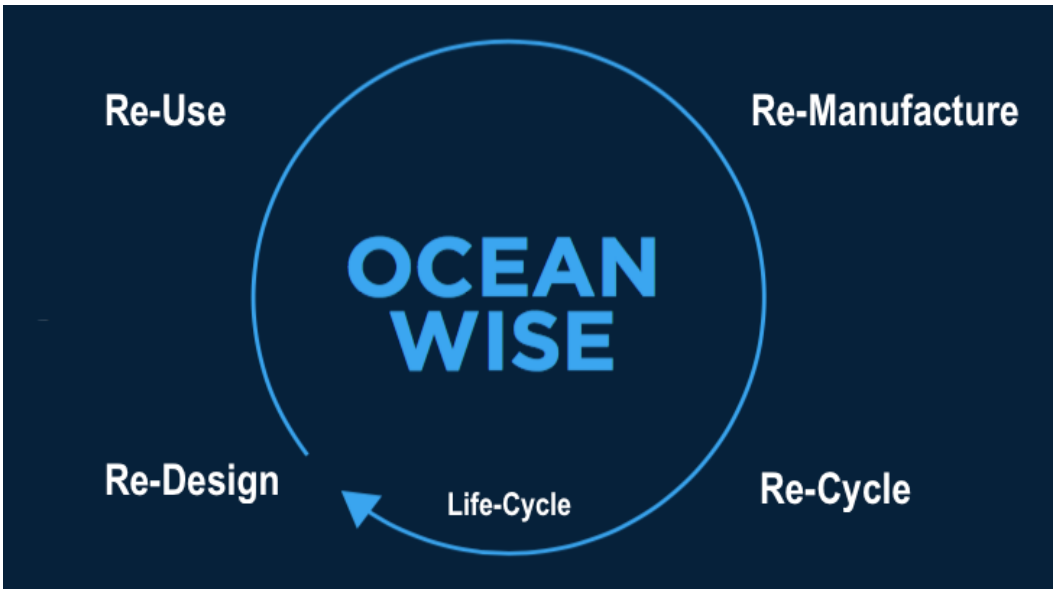



**Figure 1. Oceanwise project orientation to Circular Economy**

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.

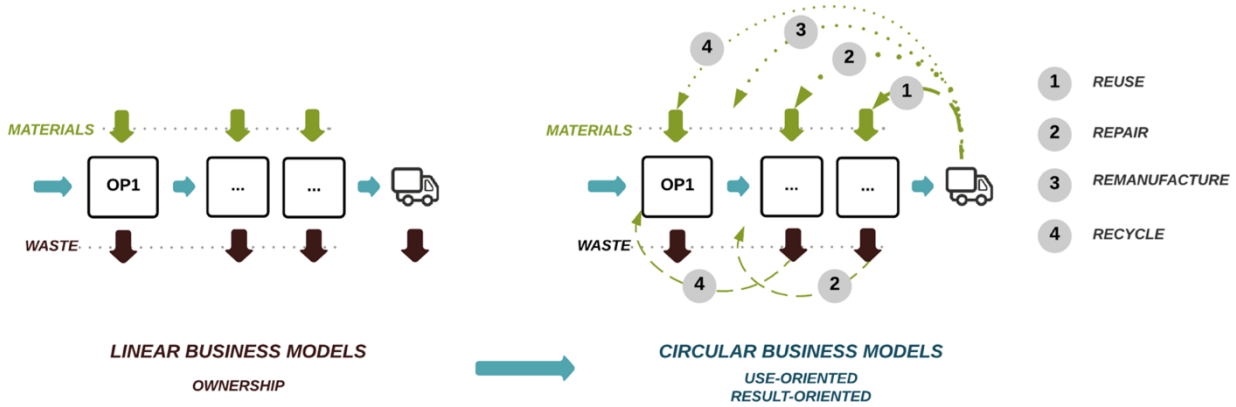



**Figure 2. Scheme of the transition from linear to circular economy production models**

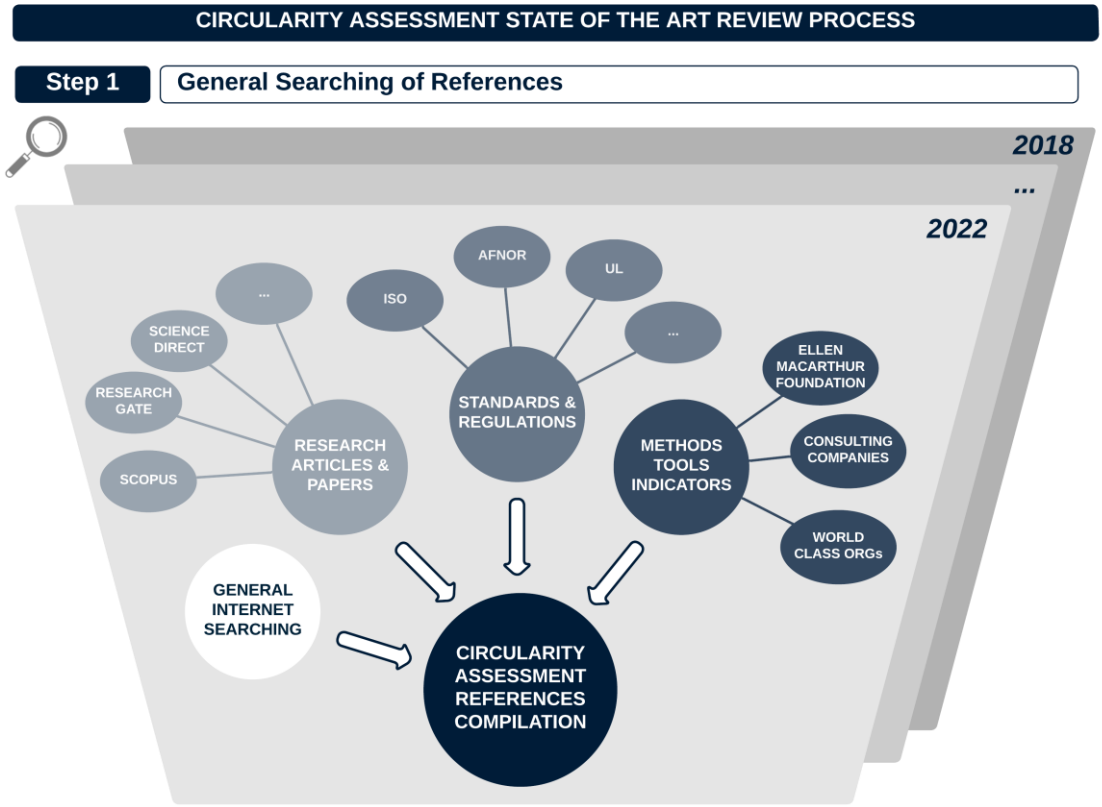
Outputs expected from WP6 are to define methodologies, models and indicators for the transition of Linear to Circular Business Models to:

- 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 Circularity Assessment state of the art review process is showed in the following figure.




| | | Applicability | | | Life Cycle Approach | | | | | | Circularity | | | | | | Impacts | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| References | Document Type | Scale | Sub-Scale | Approach | Approach | DD | MAN | T&I | O&M | DIS | Recirculation | Materials | Water | Energy | Waste | ... | LCC | LCA | SLCA | LCSA |
| Reference 1 | Article | Macro | Region | Qualitative | Partial | | | | | ✓ | | | ✓ | | ✓ | | | | | |
| Reference 2 | Standard | Micro | Organization | Qualitative | Partial | | ✓ | | | | | ✓ | | | ✓ | | | ✓ | | |
| Reference 3 | Guideline | Meso | System | Qualitative | Partial | | ✓ | ✓ | | | | | ✓ | ✓ | ✓ | | | ✓ | | |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Reference n | Toolkit | Nano | Product | Quantitative | Partial | | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | | ✓ | | |

Circularity Assessment 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, tools, indicators, papers and articles related to circularity assessments of products.

**Figure 3. Overview of the Circularity Assessment 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 perform circularity assessments of different scopes, such as regions, systems, products, components, etc. Searching is focused on the following sources:

- General internet searching

  Initially, the general searching has been done through the keyword "circular economy" in combination with "assessment", "methodology", "indicator" and "tool".

  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])

- Standards and regulations

  As the transition towards the Circular Economy is progressing, standards and regulation are being developed to guide and help implementing its principles in countries, regions and organizations. So, a specific search has been conducted, mainly focused 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
- Life Cycle Approach
- Circularity
- Impacts Measurement

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

### Step 3: Circularity Assessment References Database

At this step, all the references found are listed and organized in the *Circularity Assessment References Database*, which gives a practical overview of their applicability to Oceanwise project, giving advantages and drawbacks and extracting the main concepts to be applicable to perform the Circularity Assessment of the different EPS/XPS products and applications to be done within activity WP6.3.

Following picture shows a schematic representation of the Circularity Assessment References Database (see reference [13]), included in Annex 10.1.

| | | Applicability | | | Life Cycle Approach | | | | | | Circularity | | | | | | Impacts | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| References | Document Type | Scale | Sub-Scale | Approach | Approach | DD | MAN | T&I | O&M | DIS | Recirculation | Materials | Water | Energy | Waste | ... | LCC | LCA | SLCA | LCSA |
| Reference 1 | Article | Macro | Region | Qualitative | Partial | | | | | ✓ | | | ✓ | | ✓ | | | | | |
| Reference 2 | Standard | Micro | Organization | Qualitative | Partial | | ✓ | | | | | ✓ | | | ✓ | | | ✓ | | |
| Reference 3 | Guideline | Meso | System | Qualitative | Partial | | ✓ | ✓ | | | | | ✓ | ✓ | ✓ | | | ✓ | | |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Reference n | Toolkit | Nano | Product | Quantitative | Partial | | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | | ✓ | | |

**Table 1. Circularity Assessment 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 been repeated all along the Oceanwise project development (from 2018 to 2022, as showed in Figure 4).

Therefore, the *Circularity Assessment 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, tools, indicators, papers and articles related to circularity assessments of products. See an overview of the contents of the database in the following figure.

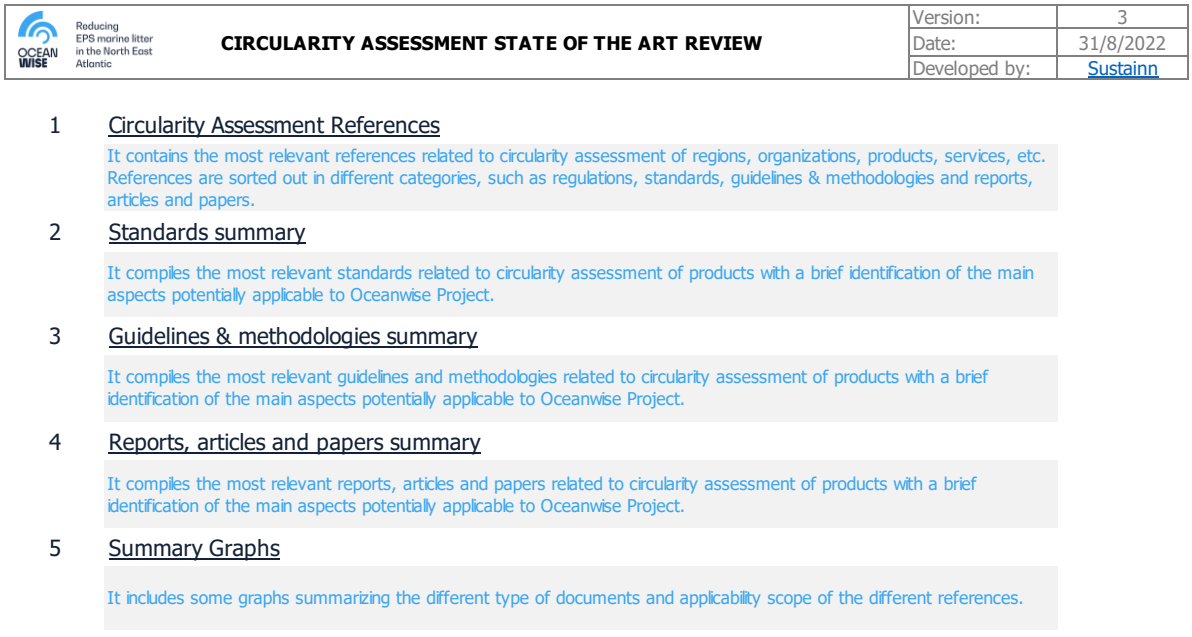



**Figure 4. Index of contents of Circularity Assessment References Database**

Final aim of the state of the art process is to provide as much information as possible to perform circularity assessment of the different EPS/XPS products and applications defined as target within Oceanwise project.

# 7 STATE OF THE ART ANALYSIS

The following subchapters describe the analysis of the different circularity assessment 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 life cycle approach, circularity and impacts measurement to consider for the development of the methodology to perform circularity assessment of EPS/XPS products and applications, defined as targets 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 circularity assessment references found. These are the aspects defined:

- Document Type
- Applicability Scope
- 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 sustainability or circularity assessment.

- **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 scale of application of the different references, the specific applicability to Oceanwise targets (EPS/XPS products and applications), as well as the qualitative or quantitative approach and certifiability.

- **Scale and sub-scale**. Scope of application of the references, addressing these different levels and sub-levels:
    - Macro: this is the highest level where cities, countries and international agencies reside. Sub-scale levels considered herein are:
        - Country
        - Region
        - City
    - Meso: it represents all inter-industries, eco-industrial parks and inter-firm networks. Sub-levels considered are:
        - Industrial Area/Park
        - System
    - Micro: this is the level where organizations, companies and consumers stand. Sub-levels herein:
        - Administration
        - Company
        - Business Model
    - Nano: this is the lowest level of analysis possible at which products and components belong. Not all researches and publications include this level as the related goals and actions are usually taken at a higher level. Sub-levels are:
        - Product
        - Component
        - Material

  Definitions about scale levels are extracted from reference [14].

- **Applicability to OW Project Target**. It evaluates if the reference is applicable to OW project target
    - Direct, if the aspects described in a particular reference can be applied directly to the project target
    - Indirect, if some aspects explained in a reference can be adapted to the project target

- **Approach**. It evaluates if any reference proposes a qualitative or quantitative assessment. Some of the references could be qualitative in some parts and quantitative in others.

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

### 7.1.3 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 the whole life cycle

- **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.

International Standard IEC 60300-3-3 (see reference [16]) 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 *Circularity Assessment Reference Database*, CD and DD phases are combined 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, including transportation to distributors or final user. 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

- 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,

- 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.

Evaluation of the product life cycle phases addressed within the references is done according to the definition of product life cycle phases given in this standard.

### 7.1.4 Circularity

In this area, different aspects are defined to assess if the different references evaluate the circularity of a region, company, business model, service or product and its components.

- **Recirculations**. It evaluates if a reference is considering the following recirculations of products, components and materials, as:

  - Repair or maintenance
  - Reutilization or reuse
  - Renovation or refurbishing
  - Remanufacturing
  - Recycling

A description of these recirculations is given in the Circular Economy System Diagram, explained in reference [17].

- **Materials**. It evaluates if a reference is considering aspects related to:
  - Selection and utilization of renewable materials
  - Properties of materials (biodegradability, recyclability, etc)
  - Efficiency on the utilization of materials
  - …
- **Water**. Considering aspects related to consumption, recirculation and water footprint.
- **Energy**. Considering aspects related to type of energy source used, consumption and efficiency.
- **Wastewater**. Considering aspects related to the generation of waste water and its polluting load.
- **Emissions**. Considering aspects related to the generation of emmissions, its polluting load and carbon footprint.
- **Noise**. Considering aspects related to the generation of noise.

### 7.1.5 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 a overall index to assess sustainability (economical, environmental and social) or circularity of the object analyzed.

## 7.2 ANALYSIS OVERVIEW

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

A total of 94 relevant references have been found worldwide related to the combination of searching terms defined in chapter 6, within this state of the art review of circularity assessment references.

Following the steps defined before in the analysis overview, general findings related to the different analysis criteria 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 50 articles, reports 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 13 of these references are standards developed by normalization, standardization bodies and recognized organizations and institutions, showing that the circular economy is just at the starting point from the point of view of the legislation and regulations.

No specific regulations or legislations to perform circularity assessments of products have been developed yet.

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

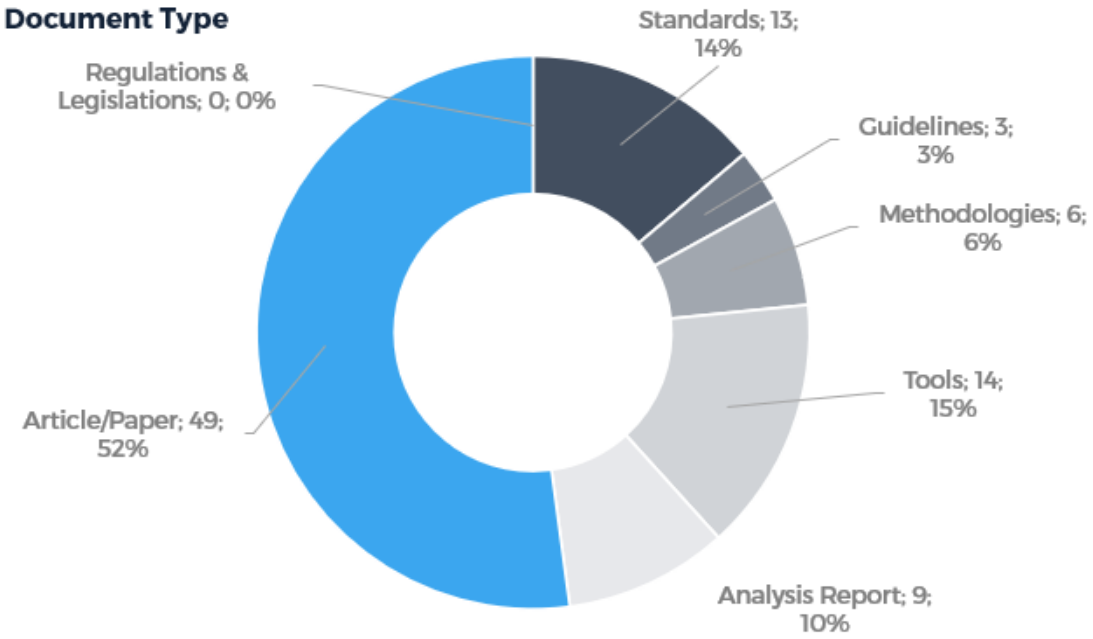



**Figure 5. Type of Documents**

Sections 7.2.6 to 7.2.8 show an evaluation of the different standards, guidelines, methodologies, tools, reports, articles, research papers and other references.

### 7.2.2 Applicability Scope

General findings about applicability scope of the references are described below, specifically about scale and subscale, applicability to OW project target, quantitative/qualitative approach and certifiability.

**Scale/Subscale**

Very diverse applicability scale and subscale are found among all the references studied, analysing very different aspects related to the implementation of circular economy to regions, cities, organizations and products.

Next figure shows the distribution of scale and subscale levels of applicability scope. Some of the references apply to different scale/subscale.

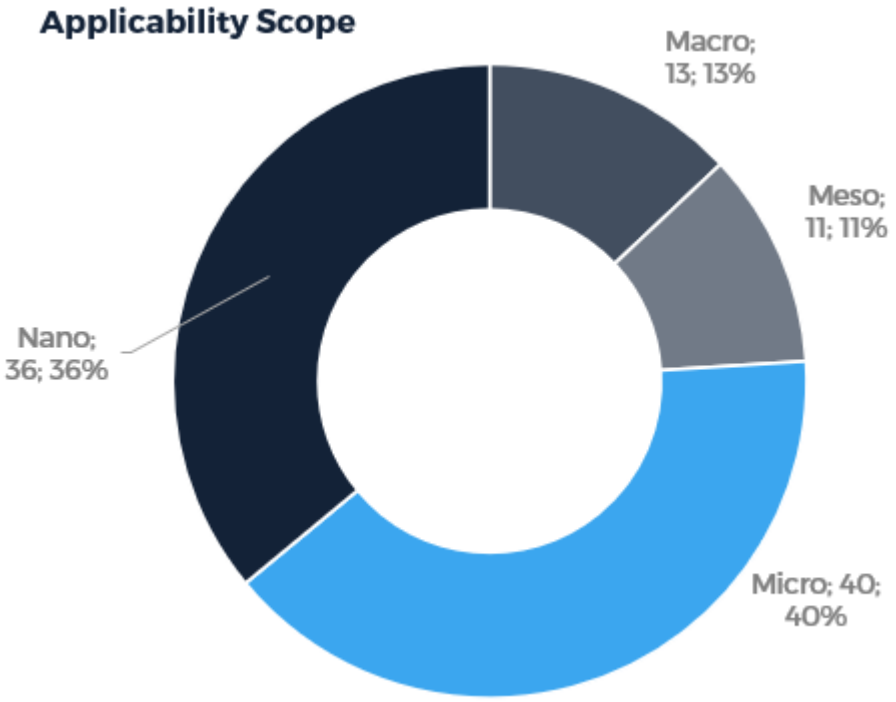



**Figure 6. Applicability Scope**

To point out that the references focused on a product or component level have been increasing during the last years (Nano, 36%).

The state of the art analysis has been focused on existing circularity assessment standards, guidelines, methodologies and tools in a nano scale, specifically for a company and product 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 meso or macro scale levels that could be used for the circularity assessment of EPS/XPS products and applications are extracted for the recommendations to be considered to perform a circularity assessment of EPS/XPS products and applications, explained in chapter 8.

**Applicability to OW Project Target**

Regarding applicability to OW project, both direct and indirect applicability of the different references are analysed aiming to see if a particular reference could be applied partially or completely to the OW project target.

Most of the references are very generic, not focusing on a particular kind of product or component.
Very few references found could be applied directly to EPS or XPS products and applications.

**Quantitative/Qualitative Approach**

Quantitative/Qualitative approach of the different references is analysed aiming to see if there are references that could be used partially or completely to the OW project target. Most of them are describing qualitative approaches.

Since a circularity assessment of a product should quantify and measure some indicators related to circularity, references with quantitative approach are preferred to analyse in detail within this state of the art review process.

As an exercise using the *Circularity Assessment References Database*, the following extract shows those references from the database focusing at a micro or nano level, applicable to products or components that can be applicable directly to OW project and have a quantitative approach.

| | | | | | APPLICABILITY | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Area / Reference | Developer | Reference Title | Date | Document Type | Scale (1) | Sub-Scale (1) | Applicability to OW Project Target | Approach (Qualitative, Quantitative) | Certifiable? |
| 1.1 | ISO | ISO 14040. Environmental management. Life cycle assessment. Principles and framework | 2006 | Standard | Nano | Product | Direct (for EPS and XPS products) | Quantitative | No |
| 1.2 | ISO | ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines | 2006 | Standard | Nano | Product | Direct (for EPS and XPS products) | Quantitative | No |
| 1.8 | UL | UL 3600. Outline of Investigation for Measuring and Reporting Circular Economy Aspects of Products, Sites and Organizations | sep-18 | Standard | Nano | Sites/Products | Direct (for EPS and XPS products) | Quantitative | Yes |
| 1.10 | Cradle to Cradle Products Innovation Institute | Cradle to Cradle Certified™ Product Standard | Vs 3.1. 2014 | Standard | Nano | Products: Materials, sub-assemblies, and finished products | Direct (for EPS and XPS products) | Quantitative | Yes |
| 2.6 | EMF (Ellen Macarthur Foundation) & Granta Design | Material Circularity Indicator of a Product (MCIP), Circularity Indicators Project (CIP) | may-15 | Tool | Nano | Product/Organization | Direct (for EPS and XPS products) | Quantitative | No |
| 2.7 | Sustainn | Circularity Assessment: How to explore business opportunities towards Circular Economy in your company | may-16 | Methodology | Micro | Organization/Business Model/Product | Direct | Quantitative | NO |
| 2.10 | IDEAL&CO Explore | Circularity Calculator | 2018 | Tool | Nano | Product | Indirect | Quantitative | No |

**Figure 7. Example of Exercise Results in Circularity Assessment References Database**

## Certifiability

Certifiability is analysed to know if circularity assessment of 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, there is no regulation in place to get a specific certification of the circularity assessment of any product. However, standards listed in the following figure could be used as a reference to achieve certifications of organizations, products, components or materials, related to eco-efficiency, EPD (environmental product declaration), carbon footprint, waste and cradle to cradle ®.

| ID | Standard | Developer | Subscale | Certifiability |
|---|---|---|---|---|
| 1 | ISO 14045: Environmental management — Eco-efficiency assessment of product systems — Principles, requirements and guidelines | ISO | Product | Y |
| 2 | ISO 14025:2006 Environmental labels and declarations — Type III environmental declarations — Principles and procedures | ISO | Product | Y |
| 3 | ISO/TS 14067:2013 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification and communication | ISO | Product | Y |
| 4 | XP X 30-901. Circular economy - Circular economy project management system - Requirements and guidelines | AFNOR | Administration Organization | Y |
| 5 | UL 3600. Outline of Investigation for Measuring and Reporting Circular Economy Aspects of Products, Sites and Organizations | UL | Sites/Products | Y |
| 6 | Residuo Cero | AENOR | Organization | Y |
| 7 | Cradle to Cradle Certified™ Product Standard | Cradle to Cradle Products Innovation Institute | Products: Materials, sub-assemblies, and finished products | Y |
| 8 | Plastic Waste Reduction Standard | Verra | Organization | Y |
| 9 | Eco-Management and Audit Scheme | European Commission | Organization/Business Model | Y |

**Figure 8. Standards and Guidelines for certification**

### 7.2.3 Life Cycle Approach

A circularity assessment of a product or component should be focused on its complete life cycle considering all the life cycle phases described previously in section 7.1.3.

In general, just very few of the references analysed are considering the full life cycle approach.

Since a circularity assessment of a 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 the circularity assessment of EPS/XPS products and applications.

### 7.2.4 Circularity

A circularity assessment of a product should consider all the aspects related to circularity defined previously in sub-chapter 7.1.4 (recirculations, materials, water, energy, etc). Despite that, any mention to a specific of those aspects is compiled to build a complete circularity assessment methodology for EPS/XPS products and applications.

A high diversity of aspects related to Circular Economy (waste, water, energy, etc) is found in the references. Most of references are focused on some of these specific aspects, but few of them are including all the circularity aspects defined previously and defining indicators aligned to measurement of circular economy principles.

### 7.2.5 Impacts Measurement Indexes

And finally, inclusion of indexes and indicators measuring environmetal, economic 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 [29]) 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 *Circularity Assessment References Database* for the assessment of the references found has been built. See Annex 10.1

Following sections show 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.

### 7.2.6 Standards

A remarkable development of standards related to the implementation of circular economy within organizations has been carried out recently by standardization, normalization and recognized bodies. The most relevant ones found are:

- **ISO 14040:2006** Environmental management - Life cycle assessment - Principles and framework (see reference [15]).
- **ISO 14044:2006** Environmental management — Life cycle assessment — Requirements and guidelines (see reference [19]).
- **ISO 14025:2006** Environmental labels and declarations — Type III environmental declarations — Principles and procedures (see reference [20]).
- **ISO 14067:2018** Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification and communication (see reference [21]).
- **BS 8001**. BSI. British Standard, Implementing Circular Economy in Organizations Framework (see reference [22]).
- **XP X30-901** Octobre 2018, AFNOR. Economie circulaire - Système de management de projet d'économie circulaire - Exigences et lignes directrices (see reference [23]).
- **UL3600** September 2018. Outline of Investigation for Measuring and Reporting Circular Economy Aspects of Products, Sites and Organizations (see reference [24]).
- **Residuo Cero.** AENOR (see reference [25]).
- **Cradle to Cradle Certified™ Product Standard**, from Cradle to Cradle Products Innovation Institute (see reference [26])

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

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

| ID | Standard | Developer | Subscale | Life Cycle Approach | Main Applicable Aspects to OW Project |
|---|---|---|---|---|---|
| 1 | ISO 14040. Environmental management. Life cycle assessment. Principles and framework | ISO | Product | Full | Definition of Environmental Impact of the complete life cycle of a product |
| 2 | ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines | ISO | Product | Full | Requirements and guidelines for life cycle assessment (LCA) |
| 3 | ISO 14045: Environmental management — Eco-efficiency assessment of product systems — Principles, requirements and guidelines | ISO | Product | Full | Requirements and guidelines for eco-efficiency assessment for product systems |
| 4 | ISO 14025:2006 Environmental labels and declarations — Type III environmental declarations — Principles and procedures | ISO | Product | Full | To consider to get EPD of a product |
| 5 | ISO/TS 14067:2013 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification and communication | ISO | Product | Full | To consider to calculate a product life cycle emissions |
| 6 | BS 8001 Circular Economy | BSI | Company | Full | Principles to implement Circular Economy within an organization and guidance on product design and development of products, materials selection, and reverse logistics |
| 7 | XP X 30-901. Circular economy - Circular economy project management system - Requirements and guidelines | AFNOR | Administration Organization | Full | - Triple Impact: consideration of 3 dimensions of sustainable development (economical, environmental and social)<br>- Guidance on sustainable procurement, ecodesign and product lifetime extension |
| 8 | UL 3600. Outline of Investigation for Measuring and Reporting Circular Economy Aspects of Products, Sites and Organizations | UL | Sites/Products | Partial | - Product Content (upstream) vs Product Design (donstream)<br>- Product Circularity Score<br>- Corporate Circularity Score |
| 9 | Residuo Cero | AENOR | Organization | Partial | - Inventory and traceability of waste from production to final destination<br>- Waste Minimization and Valorization Plans |
| 10 | Cradle to Cradle Certified™ Product Standard | Cradle to Cradle Products Innovation Institute | Products: Materials, sub-assemblies, and finished products | Partial | - Material Health measurement<br>- Material Reutilization Score<br>- Water Stewardship<br>- Energy Management<br>- Social Fairness |
| 11 | Plastic Waste Reduction Standard | Verra | Organization | Partial | Procedures for quantifying the plastic waste collected and/or recycled |

**Table 2. Circularity Assessment related standards**

Main aspects to consider are:

- ISO 14000 series
  - ISO 14040 defines principles and framework for an environmental life cycle assessment
  - ISO 14044 specifies requirements and provides guidelines for life cycle assessment (LCA)
  - ISO 14025 establishes the principles and specifies the procedures for developing Type III environmental declaration programmes
  - ISO 14067 specifies principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product (CFP)
- All the standards present a quantitative approach for some aspects, that should be studied to develop circularity assessment for OW project, such as Cradle to Cradle indicators and product circularity score from UL3600
- Measuring environmental impact is a requirement to certify a product or organization although there are not specific overall environmental goals or indicators defined.
- There are some formulas to calculate circularity of a product (UL3600) focusing on materials, but they are not considering the complete life cycle as defined herein this document and some aspects like emissions, energy and water. So, you can not know how circular is an organization or product in a widest extension.
- The 3 dimensions of sustainable development (economical, environmental and social) are to be considered to analyze circularity and sustainability, according to XP X30-901.
- Plastic waste reduction standard from Verra establishes rules and methodologies to quantify and account for the collection and/or recycling of waste, incorporate social safeguards to protect project actors, and implement a verification system.

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.

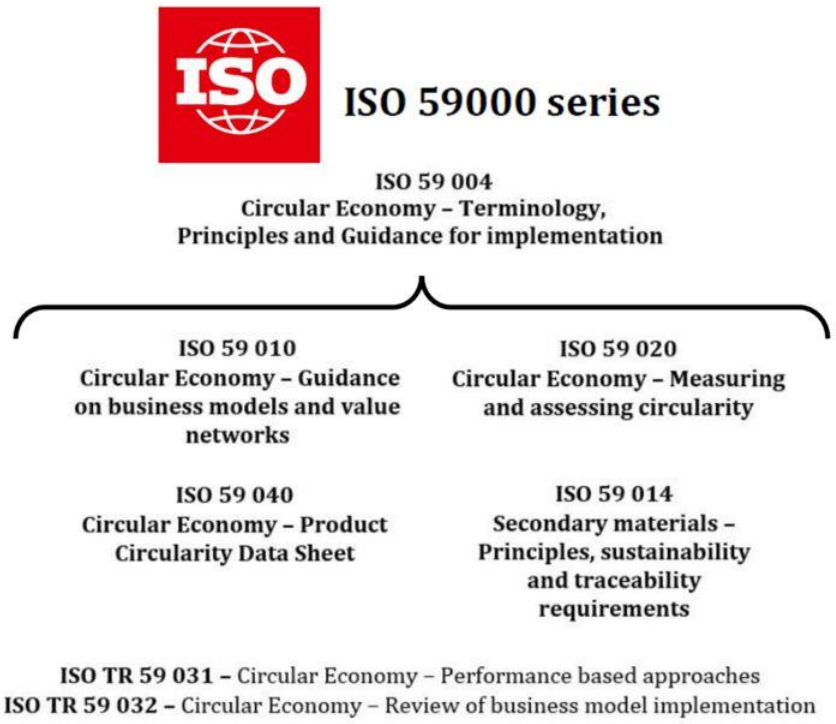



**Figure 9. Future series of ISO 59000 standards on Circular Economy**

The future ISO 59020 (see reference [27]) in combination with the rest of the listed ISO's on circular economy should be considered in the future to perform circularity assessments of EPS/XPS products and applications.

### 7.2.7 Guidelines, Methodologies and Tools

This section evaluates most relevant guidelines, methodologies and tools 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 economic model.
Organizations, projects and institutions contributing to the development of the most relevant guidelines, methodologies and tools found are:

- United Nations Environmental Program (UNEP)
- Ellen Macarthur Foundation – new tool called 'Circulytics' launched in February 2020
- European Commission, with the collaboration of BIO Intelligence Service
- European Commission, with EMAS
- Organization for Economic Co-operation and Development (OECD)
- World Business Council Sustainable Development (WBCSD)
- European Academies Science Advisory Council (EASAC)
- Universities such as,
  - University of Cambridge, Institute for Manufacturing (IfM), from England
  - Royal Institute of Technology, from Sweden
  - Technical University of Denmark
- Private companies, such as:
  - Circle Economy
  - KPMG
  - Sustainn
  - IDEAL&CO Explore
  - Liberty Global
- Projects as ORIENTING

The following table shows most relevant aspects of considered top 10 guidelines, methodologies and tools related to circularity assessment and circular economy implementation after the state of the art analysis performed in this activity, such as:

- Developer
- Document type (guideline, methodology, tool). References defining indicators are considered as methodologies.
- Subscale
- Life cycle approach
- Main applicable aspects to OW project target

| ID | Reference Title | Developer | Document type | Subscale | Life Cycle Approach | Main Applicable Aspects to OW Project |
|---|---|---|---|---|---|---|
| 1 | Circularity Assessment for Organizations | Circle Economy | Tool | Organization | - | - Aspects related to materials, energy and labor: Renewability, recyclability, criticality, geopolitical risk, locality, competition<br>- Global impacts on land, water, atmosphere and society |
| 2 | Circulytics | Ellen Macarthur Foundation | Tool | Enterprises | Partial | Measures a company's entire circularity, not just products and material flows<br>Supports decision making and strategic development for circular economy adoption<br>Demonstrates strengths and highlights the areas for improvement |
| 3 | Circularity Assessment: How to explore business opportunities towards Circular Economy in your company | Sustainn | Methodology | Organization/Business Model/Product | Full | - Analysis of design and development processes<br>- Life cycle cost assessment to evaluate competitiveness |
| 4 | Material Circularity Indicator of a Product (MCIP), Circularity Indicators Project (CIP) | EMF (Ellen Macarthur Foundation) & Granta Design | Tool | Product/Organization | Partial | - Material Circularity Indicator of a product<br>- Complementary risks indicators<br>- Company Level Aggregator tool |
| 5 | Circular IQ | KPMG, Circle Economy and MVO NL | Tool | Suppliers<br>Product<br>Material | Partial | See how circularity index has been built and could be applicable to EPS/XPS products and applications |
| 6 | Circularity Calculator | IDEAL&CO Explore | Tool | Product | Full | Consider circularity performance KPI's (circularity indicators, value capture, recycled content, reuse index) |
| 7 | Sustainability Score | Positively Sustainable | Methodology | Product | Partial | Simple method to consider how it rates every indicator and how sustaianability score is built |
| 8 | Product Sustainability Scorecard<br>Improving the sustainability performance of every new customer product | Liberty Global | Methodology | Product | Partial | Environmental and social issues most relevant for customer products are considered.<br>Internal and external stakeholder interviews to identify the most important impact areas.<br>Check the selected environmental and social issues considered.<br>Important the weighting criteria considered |
| 9 | Circularity Check | WeSustain Ecopreneur.eu | Tool | Product | Partial | Consider how sustainability index is built |
| 10 | Readiness Assessment Tool for the Circular Economy of MATChE | Technical University of Denmark | Tool | Organization | - | Interesting the different tools that this tool provides to make a circular economy transition |

**Table 3. Circularity Assessment Guidelines, Methodologies and Tools**

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

- Guidelines, methodologies and tools to perform circularity assessment give guidance to analyse circularity of regions, organizations, products and manufacturing processes, and can not be used to certify a organization or product.
- In general, guidelines, methodologies and tools 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 circularity assessment guidelines, methodologies and tools.
- Environmental impact, cost impact and social impact can be measured and developed through LCA, LCC and SLCA indicators.
- Indicators to measure circularity should be oriented to measure financial, environmental and social performance and an overall index should be defined to measure circularity and sustainability.
- Aspects related to resource use-oriented and to global impacts on land, water, soil and atmosphere should be considered within environmental impact indicators.
- All recirculation loops of products, components and materials (repair, reutilization, refurbishing, remanufacturing an recycling) are to be considered.
- During the last years more tools to perform a circularity assessment of a product have been developed. To point out Circularity Calculator tool (see reference [28]), which allows evaluating circularity of the whole product life cycle, starting with the materials used to make the product, their manufacturing into parts, the assembly of the product, the use phase, and the different linear and circular strategies that can follow after the use phase.
- Remarkably, the H2020 project "ORIENTING" (reference [29]), 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.

### 7.2.8 Reports, Articles, Papers and other References

There has been found a great analysis and research activity in the field of circular economy implementation and circularity assessment of regions, organizations, business models and products.

This analysis and research activity is oriented mainly to the following areas:

- State of the art compilation about circularity assessment methodologies, guidelines and tools
- Analysis of implementation of circular economy in regions and cities
- Definition of metrics and indicators for measuring circular economy implementation, resource utilization efficiency, longevity, reutilization, etc.
- Methodologies and tools to evaluate and measure sustainability of a life cycle of a product, mainly related to life cycle sustainability assessment

The following table shows the most relevant analysis reports, articles, papers and other references oriented mainly to the definition of metrics and indicators to be considered for the development of methodologies to perform a circularity assessment of EPS/XPS products and applications.

- Developer
- Document type (analysis report, paper, article)
- Subscale
- Main applicable aspects to OW project target

| ID | Reference Title | Developer | Document type | Subscale | Main Applicable Aspects to OW Project |
|---|---|---|---|---|---|
| 1 | Circular Economy: A Critical Literature Review of Concepts | CIRAIG | Analysis Report | General | Broad review of the different concepts related to sustainability, green economy, circular economy and different methodologies and tools at a company level. |
| 2 | Ecocosts-value ratio (EVR) | Scheepen s, Vogtlände r, Brezet (2016) | Paper | Products: Materials, sub-assemblies, and finished products | - Measurement of environmental costs. Method of eco-costs<br>- Eco-efficiency factors<br>- Ecocots-value ratio (EVR) |
| 3 | Eco-Efficiency Index (EEI). An eco-efficiency methodology applied to the fish canning industry | Jara Laso, Isabel García-Herrero et.al. | Paper | Organization | - Combination of LCA and LCC to propose a eco-efficiency methodology assessment<br>- Weighting of environmental (Global Warming Potential, Acidification Potential, Eutrophication Potential and the ReCiPe Single Score Endpoint) and economic (Value Added) indicators |
| 4 | Metric for quantifying product-level circularity | Linder, Sarasini, van Loon (2017) Viktoria Swedish ICT, 2015 | Paper | Organization/Business Model/Product | - Material: LCA or MFA tools to assess material use and environmental impacts<br>- Costs: cost savings due to reduction of material costs<br>- Value retained: portion of added value that comes back to the company<br>- Recirculation: costs of input coming from reuse, recycle, remanufacturing |
| 5 | Expanded Polystyrene Packaging Environmental Profile Analysis | Alliance of Foam Packaging Recyclers | Analysis Report | Product | Case study about and EPS vacuum cleaner packaging |
| 6 | Creating a Sustainability Scorecard as a predictive tool for measuring the complex social, economic and environmental impacts of industries, a case study: Assessing the viability and sustainability of the dairy industry | Buys, Laurie, Mengersen, Kerrie, Johnson, Sandra, Van Buuren, Neil, & Chauvin, Anita | Paper | Industry | Sustainability Scorecard Bayesian network for farm, factory and market. Able to operate in a predictive or diagnostic way.<br>Stakeholders engagement to design the Bayesian network.<br>BNs are 'quantified' by assigning conditional probability distributions to the nodes |
| 7 | Exploring the Current Challenges and Opportunities of Life Cycle Sustainability Assessment | Rizal Taufiq Fauzi, Patrick Lavoie, Luca Sorelli, Mohammad Davoud Heidari and Ben Amor | Paper | Product | LCSA is now accepted as an assessment method to support decision making on sustainability.<br>To consider the crossover research challenges to analyse around LCSA, about:<br>- The Integration of LCA and LCC<br>- The Integration of LCC and S-LCA<br>- The Integration of S-LCA and LCA<br>See research opportunities (important for the conclusions of WP6.1) |
| 8 | Measuring the environmental performance of a circular system: Emergy and LCA approach on a recycle polystyrene system | Henrique Rogerio Antunes de Souza Junior, Thales Eduardo Tavares Dantas, Guilherme Marcelo Zanghelini, Edivan Cherubini, Sebastião Roberto Soares | Paper | Product | EMA (Emergy Analysis).<br>'Results have demonstrated that a production system established based on circular economy principles will not always have a better environmental performance for all environmental impact categories. |
| 9 | Life cycle sustainability assessment: A systematic literature review through the application perspective, indicators, and methodologies | Caroline Visentin, Adan William da Silva Trentin, Adeli Beatriz Braun, Antônio Thomé | Paper | Product | Complete assessment of publications related to LCSA<br>See Environmental, economic, and social indicators most used.<br>See main sustainability analysis methodologies used (MDCA, MAVT, MCDM, etc).<br>See future directions of LCSA studies. There is still no universal methodology for LCSA |
| 10 | Normalization in sustainability assessment: Methods and implications | N.L. Pollesch, V.H. Dale | Paper | Several potential applications | See exposed normalization methods.<br>Consider indicators bearings (large the better, smaller the better, distance to ideal). |
| 11 | Critical evaluation of material criticality and product-related circularity approaches | Orienting Project | Report | Product | State of the art report of methods related to materials criticality and product circularity |
| 12 | Critical evaluation of sustainability integration approaches | Orienting Project | Report | Product | Best available approaches for LCSA combining environmental, social, economic analyses together with materials criticality and product circularity |

**Table 4. Circularity Assessment Analysis Reports, Articles, Papers and other References**

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

- The analysis report "Circular Economy: A Critical Literature Review of Concepts", from CIRAIG gives a broad understanding of the different concepts related to sustainability, green economy, circular economy and different methodologies and tools at a company level.
- A lot of articles have been found studying state of the art of about of circularity assessment on regions, organizations and products.
- Most references found 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 with a social approach or a social impact measurement included as a part of circularity assessment.
- A lot of references are studying different ways of measuring resource efficiency, material retention, reuse potential of waste, waste input and output, cost and value added.

- A remarkable research activity about life cycle sustainability assessment (LCSA) of products has been carried out in the last years. LCSA has been applied in many sectors, including transportation, building, energy, agriculture, manufacturing, and waste treatment. The increasing number of publications on this topic, and the diverse applications of case studies, shows that LCSA is increasingly accepted as an assessment method to support decision making on sustainability. However, some challenges and opportunities to improve LCSA methodology are identified (more information in reference [30]), such as:
  - The Integration of LCA and LCC
  - The Integration of LCC and S-LCA
  - The Integration of S-LCA and LCA
- Project ORIENTING (reference [29]) 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

## 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 on analysing how the circular economy principles are being implemented in regions, cities, organizations and products, studying the different literature about how to perform a circularity assessment of organizations and products.

As a general conclusion, no methodology or reference developed adhoc for EPS/XPS has been found at this moment to carry out a circularity assessment of EPS/XPS products and applications. However, a lot of relevant aspects can be used to develop an specific methodology and tools to perform it combining circularity and sustainability assessments, considering LCC, LCA and SLCA approaches. 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 no specific regulations have been developed yet to perform circularity assessment of products.
  There is great research activity in this field (more than 50 relevant articles, papers and reports found) and a remarkable effort is being done around the world to develop standards, guidelines and methodologies to assess circularity of territories, cities, organizations, products and components.

  Remarkably, first drafts of ISO 59000 series on circular economy are under development to help measure circularity of organizations and products.

- **Applicability scope**

  Very diverse applicability scale (macro, meso, micro, nano) are found among all the references studied, with an increasing interest focused on a product or component level (around 35% of references).

Regarding certifiability, just the following standards can be used to certify an organization or product regarding different aspects:

- ISO 14045: Environmental management — Eco-efficiency assessment of product systems — Principles, requirements and guidelines
- ISO 14025:2006 Environmental labels and declarations — Type III environmental declarations — Principles and procedures
- ISO 14067:2018 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification
- XP X 30-901. Circular economy - Circular economy project management system - Requirements and guidelines
- UL 3600. Outline of Investigation for Measuring and Reporting Circular Economy Aspects of Products, Sites and Organizations
- Residuo Cero
- Cradle to Cradle Certified™ Product Standard
- Plastic Waste Reduction Standard
- Eco-Management and Audit Scheme (EMAS)

There is no standard yet to achieve a certification of the circularity of a particular product. Future ISO59020 (Circular Economy "Measurement and evaluation of circularity") and ISO59000 series should be taken into consideration for certification of circularity of products in the next years.

- **Life cycle approach**

Most of the methodologies, tools, metrics and indicators are considering some particular phases of the life cycle of a product or service, but very few are considering the full life cycle.

- **Circularity**

A high diversity of aspects related to Circular Economy (waste, water, energy, etc) is found in the references. Most of references are focused on some of these specific aspects, but few of them are including all the circularity aspects defined previously and defining indicators aligned to measurement of circular economy principles.

Note that there are some references summarizing the state of the art of tools and methodologies to perform a circularity assessment of products, highlighting among them the Circularity Calculator tool (see reference [28]), which allows evaluating circularity of the overall product life cycle, starting with the materials used to make the product, their manufacturing into parts, the assembly of the product, the use phase, and the different linear and circular strategies that can follow after the use 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, such as resource use efficiency, reutilization potential, etc

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 in a simple way a global 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. Orienting project is developing a comprehensve methodology based on LCSA approach combining environmental LCA, social LCA and life cycle costing, and integrating assessment of product circularity.

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

- ISO 14040 defines principles and framework for an environmental life cycle assessment.
- In most cases, references are focused on an specific life cycle phase or specific indicator, and in particular, design and development phase of the life cycle is rarely considered. In general, the studied references rarely consider a full life cycle perspective as defined in this document
- The development of ISO 59000 standard series for the implementation of circular economy in organizations and products is on going. The future ISO 59020 in combination with the rest of the ISO's on circular economy should be considered in the future to perform circularity assessments of EPS/XPS products and applications.
- Guidelines, methodologies and tools to perform circularity assessment give guidance to analyse circularity of regions, organizations, products and manufacturing processes, but can not be used to certify a organization or product.
- There are some formulas, methodologies and tools to calculate and assess the circularity of a product, such as the Circularity Calculator tool, which evaluates the whole life cycle of a product, defined circularity indicators and help simulate different circular strategies.
- The 3 dimensions of sustainable development (economical, environmental and social) are to be considered to analyze circularity and sustainability, according to some standards (XP X30-901) and methodologies (LCSA approach from Orienting project). Environmental impact, cost impact and social impact can be measured and developed through LCA, LCC and SLCA indicators.
- LCSA (Life Cycle Sustainability Assessment) is increasingly accepted as an assessment method to support decision making on sustainability of alternative solutions of a product.
- LCSA approach is taken as the basis for the development of a methodology to assess sustainability of a product combining environmental LCA, social LCA and life cycle costing (LCSA = LCA + S-LCA + LCC) and integrating circularity assessment.

# 8 RECOMMENDATIONS TO PERFORM CIRCULARITY ASSESSMENT OF EPS/XPS PRODUCTS

This chapter includes the recommendations, resulting from this state of the art analysis, for the development of a methodology to perform circularity and sustainability assessment of alternative technical solutions for EPS/XPS products and applications, which is to be developed in activity 3 of the work package 6 of OW project.

As a general approach, circularity assessment of the life cycle of a product should be aligned to circular economy principles, that are:

- Principle 1: Design out waste and pollution
- Principle 2: Keep products and materials in use
- Principle 3: Regenerate natural systems

Assuming that circularity has to be sustainable, the 3 dimensions of sustainability (economical, environmental and social) are to be considered to analyze circularity and sustainability. LCSA (Life Cycle Sustainability Assessment) approach should be the main reference to follow, to combine environmental impact (LCA, Life Cycle Analysis), cost impact (LCC, Life Cycle Cost) and social impact (SLCA, Social Life Cycle Analysis).

The methodology to be developed should cover the complete life cycle of the different products and applications, according to ISO14040 (reference [15]).

Regarding **environmental impact** analysis, LCA techniques are to be followed, considering the following aspects:

- Resource-use oriented: aspects related to the materials selection and resources (water, energy) consumption and efficiency
- Waste generation: aspects related to the different kind of waste generated (hazardous, non hazardous, waste water, solids, etc)
- Circularity, where all the recirculations loops of the product, its components and materials (repair, reutilization, refurbishing, remanufacturing an recycling) are to be considered.
- Impacts on land, water, soil and atmosphere should be considered within environmental impact indicators.

In order to analyze **costs impacts** all along the value chain, life cycle cost of the product or application should be done including all its life cycle phases considering as a main reference IEC 60300-3-3 international standard (reference [16]).

Then, to analyze the **social impact** of the different alternative solutions, a wider analysis is to be done to define which aspects are to be studied, considering internal social aspects and external aspects to the company responsible for the design and development of any of these alternatives. It is recommended to follow as a reference the "Guidelines for Social Life Cycle Assessment" from UNEP (see reference [31]).

Finally, the methodology to assess circularity and sustainability of EPS/XPS products and applications should integrate circularity assessment combined with environmental, cost and social impacts analyses. It is recommended to work on the definition of an overall quantitative index that should be calculated to measure circularity and sustainability assessment of the alternative solutions for EPS/XPS products and applications.

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# 10 ANNEXES

## 10.1 ANNEX 1: CIRCULARITY ASSESSMENT REFERENCES DATABASE

CircularityAssessmentReferencesDB_R0.