D2.3: Reference methodologies and KPIs in circular economy analysis

WP , T

October, 2019 (M18)

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

[2] R = Report, P = Prototype, D = Demonstrator, O = Other ORDP = Open Research Data Pilot

Versions

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Table of Content

List of Tables

List of Figures

0 Abstract

Deliverable 2.3 "Reference methodologies and key performance indicators (KPIs) in circular economy analysis" is a public document of the HOUSEFUL project, delivered in the context of WP2 "Methodology for the evaluation of circularity in the housing sector" and it is an output of the Task 2.3 "Definition of the focussed calculation procedures and relevant KPIs for the different circular economy composing vectors".

WP2 "Methodology for the evaluation of circularity in the housing sector" aims at developing a robust, reliable and day-to-day market usable methodology to quantify the degree of circularity of buildings, both pre- and post-refurbishment, which could be used by designers but also construction companies, promoters and financial institutions. The methodology will be developed considering the main circular economy principles related to recyclability, reusability and waste savings of the materials and active solutions defining the buildings, and also other key factors such as the feasibility of circular solutions (WP5 "Environmental, economic and social assessment") offered to stakeholders as services (WP6 "HOUSEFUL Solutions as Services, market, policies and exploitation"). The methodology will con-sider all the existing or brand new methodologies related to the key vectors of circularity, including LCC, LCA, S-LCA methodologies[3] or the next future brand new EU Level(s) one. The methodology will result in an easy-to-use tool (HOUSEFUL Solution "S1"), which will be the basis of the Software as a Service (SaaS) developed in WP6.

The main Objectives of WP2 are:

- To define the main weighting factors and KPIs representatives of the recyclability and reusability of materials, of the energy and water life cycle, and of the social and economic performance;
- To define a set of rules and procedures from the existing bibliography and methodologies, and combine them in a complete and comprehensive circularity calculation methodology;
- To establish some recommended and predefined values, both for representative parameters and for required inputs, from residential building archetypes representing different European locations;
- To refine the methodology for the evaluation of circularity using the results obtained in the real demo scenarios and the other WPs, establishing a high degree of reliability."

The WP2 are divided in different subtasks from which are expected the next outcomes regarding the mentioned objectives.

- Task 2.1. Report on end-user's requirements considering different circular economy business opportunities.
- Task 2.2. Identification of the most relevant building archetypes for different EU representative geo-clusters.
- Task 2.3. Identification of the KPIs of the circularity evaluation methodology, as well as their calculation procedures.

[3] See the acronyms table in section 1.

- Task 2.4. Development of a building circularity evaluation methodology.
- Task 2.5. Definement of the building circularity evaluation methodology.
- Task 2.6. Identification and analysis of circular solutions and services already existing in the market.

According to the above, Task 2.3. refers to the definition of the focussed calculation procedures and relevant KPIs for the different circular economy composing vectors.

The aim of this task is to properly and reliably establish reference calculation methodologies for the different circular aspects and define its main KPIs. To ensure replicability a set of common core indicators is needed for making environmental, social and economic improvements to be used in decision-making through the entire life-cycle of buildings.

1 Introduction

This document collects the main existing references and relevant calculation procedures regarding circular economy and sustainable development in the housing sector. The data collection is based on literature review.

The analysis of the different sources is the base for setting the reference methodologies and KPIs in the circular analysis. The study pretends to find the gaps and highlight the inputs of the Houseful project to select the relevant KPIs to be able to measure how the residential buildings (new and refurbished) are moving forward a more circular industry.

The present deliverable is structured as follows:

Section 1: Introduction

Section 2: Circular economy overview. This section aims to give an outlook of the current framework when talking about Circular Economy (CE). It supports the general definition of circularity and the specification for buildings' circularity, that are the basis for establishing the rules of what are we looking for when selecting the KPIs.

Section 3: The construction sector towards the Circular Economy. This section resumes the main existing standards, the LEVEL(s) initiative and compile some of the European Founded projects related Circular Economy in buildings and the construction sector.

Section 4: KPIs selection

Section 5: includes the bibliography

The table 1.1 includes the list of acronyms used through the document.

CE	- Circular Economy
KPIs	- Key performance indicators
LCC	- Life Cycle Costing
LCA	- Life Cycle Assessment
S-LCA	- Social Life Cycle Assessment
SaaS	- Software as a Service
SDGs	- Sustainable Development Goals
SDI	- Sustainable development indicators
MCI	- Material Circularity Indicator
CDW	- Construction and Demolition Waste

Table 1.1: Acronyms list

2 Circular economy overview

This section offers an overview of the background schools of thoughts, frameworks, enablers related to the circular economy as an introduction to understand what are we looking for and what do we want to measure. This is the first step for going in depth in the Key Performance Indicators (KPIs) selection in circular economy analysis.

2.1 Finding a common language

The successful selection of KPIs related to building circularity needs a consistent basis that must be built by answering some questions from the beginning. That means to have a clear understanding of what circular economy aims to deal and the way to measure it.

To address this challenge important aspects have been identified (key points and / or keywords) and have been linked to bibliographic sources and extracts of them to set the context towards we are moving on.

2.1.1 What is circular economy about?

Key points:

- Why circular economy? Circular economy definition
- Circular economy is only about natural resources?
- Circular economy concept and its compatibility with the sustainable development.
- …

Related references: the specific sources are mentioned below and also listed in the section 5.

According to the Ellen MacArthur Foundation "the circular economy concept has deep-rooted origins and cannot be traced back to one single date or author. Its practical applications to modern economic systems and industrial processes, however, have gained momentum since the late 1970s, led by a small number of academics, thought-leaders and businesses". This is why the base of the circular economy concept should be tracked through different school of thoughts[4] as Cradle to Cradle, Performance economy, Biomimicry, Industrial Ecology, Natural Capitalism, Blue Economy and Regenerative Design (see Figure 2.1 for the descriptions and principles of some them).

[4] www.ellenmacarthurfoundation.org/circular-economy/concept/schools-of-thought

Table 3: Different schools of thought

School of thought	Description
Cradle to cradle (McDonough & Braungart, 2002)	Cradle to cradle is a design philosophy where all the products and processes are a nutritional supply for new products. The philosophy is focused on design for effectiveness in terms of products with a positive impact. This fundamentally differs from the traditional design focus by reducing the negative impacts.
Performance economy (Stahel, 2006)	Performance economy is a philosophy of an economy in loops. The main goals are product-life extension, long-life goods, reconditioning activities, and waste prevention. It also incorporates the importance of selling services instead of products, this idea is referred as the 'service economy'
Biomimicry (Benyus, 1998)	Biomimicry defines her approach that studies the best ideas of nature to imitate these processes and designs to solve human problems. This philosophy relies on three key principles: nature as model, nature as measure and nature as mentor.
Blue economy (Pauli, 2012)	The blue economy is an movement that brings together concrete case studies. It is a combination of ecological, social and economic sustainability. In other words, sustainability that is also good for people and the business case.
The natural step (The Natural Step, 2017)	The natural step uses systems thinking to create a sustainable world where the extraction of raw materials and the creation of unnatural material is minimized. It is also a world where all natural processes, including humans, can fulfil their basic needs.

Source: J.T. (Jesse) Rudolphi, 2018

Figure 2.1: Descriptions of some schools of thought related to CE

In this context of reflexion the concept of circular economy has the challenge of unifying many streams of thought and the consequence is that there are more than 114 circular economy definitions[5] (

Ref. 30). Some examples are listed below:

- J.T. (Jesse) Rudolphi, 2018 (Ref. 31, file page 28): "In the last decade, the prices of natural resources increased and became more volatile. This change in the supply chain makes the change towards a new system necessary (Ellen MacArthur Foundation, 2013a). In a circular economy, the added value of products is maintained for as long as possible and waste is eliminated. To thoroughly integrate the concept of a circular economy, a new way of thinking is needed that will reshape the economy. The concept of a circular economy re-imagines how the material flows that move through the economy might be closed (Prendeville, Cherim, & Bocken, 2017). The Ellen MacArthur Foundation (2013a) describes the concept of a circular economy as follows:

[5] "Sacchi et al. (2018) pointed out the lack of consensus on terminologies and definitions for the CE among scholars, politicians and practitioners investigating the trends, gaps, and convergence of the CE literature – through a sample composed of 327 academic articles. Similarly, Kirchherr et al. (2017) reviewed 114 circular economy definitions which were coded on 17 dimensions". (Michael Saidani et al., 2018).

A Circular Economy is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times. The concept distinguishes between technical and biological cycles."

- "CE is defined as "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations". Additionally, according to the EMF (2013), the CE is based on three shared principles, which can be summarized as it follows: (i) design out waste and pollution, (ii) keep products and materials in use, and (iii) regenerate natural systems. (Michael Saidani et al., 2018) (Ref. 30).

- "A particular interest of the circular economy concept lies in its compatibility and consistency with sustainable development, through its three associated pillars. Indeed, it aims directly not only at economic benefits (e.g., value creation and savings by reducing the purchase of primary raw materials), but also at environmental benefits (e.g., impact reduction) and indirectly at social benefits (e.g., job creation)". (Michael Saidani et al., 2017) (Ref. 32).

- A circular economy is based on a fundamental transformation of the economic system, reaching from different business models, different design- and production models to radically different consumption patterns and culture. (Rau, Oberhuber, Louiws).

- Increasingly circular economy concepts also comprise a social dimension based on the notion of an inclusive economy. (Rau, Oberhuber, Louiws)

- "CE has the potential to understand and implement radically new patterns and help society reach increased sustainability and wellbeing at low or no material, energy and environmental costs." (Ref. 2 Ghisellini, et al. 2015).

In addition to the previous definitions, the following information, extracted from Jeroen Verberne's graduation thesis briefly summarizes the main research on the definition of circular economy, clearly contextualizing what the current situation is. Below there is and extract of the mentioned document (Ref. 27): Building Circularity Indicators. An approach for measuring circularity of a building[6], Jeroen Verberne, 2016

(…) "*A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates*

[6] See file page number 17

the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems and business models ". Ellen MacArthur Foundation (2014)

"*The circular economy is a generic term for an industrial economy that, by design or intention, is restorative and eliminates waste. Material flows are of two types; biological nutrients, designed to re-enter the biosphere safely, and technical nutrients (nonbiological materials), which are designed to circulate at high quality, with their economic value preserved or enhanced*". Aldersgate Group (2012)

"*A circular economy preserves the value added to the products for as long as possible and virtually eliminates waste. The resources are retained within the economy when a product has reached the end of its life, so that they remain in productive use and create further value*". European Commission (2014a)

"*The circular economy can be defined as an industrial economy with an resiliency as intention has and consumption where it is possible changes into usage. The circular economy is based on closing the loops and to (where possible infinite) extend a cycle. It invites therewith to more use of renewable energy, minimalize the pressure on the ecological system, eliminate the use of toxic substances, and assumes that waste is the start of the next phase of life and that reuse is included in the design phase*". OPAi & MVO (2014)

In an 'ideal' world, waste would be excluded from earth which is often called in literature as a 'Zero Waste' world. It is certainly idealistic, but that something has to change is undeniable. Since the industrial revolution, our current linear economic system is based on virgin materials taken from nature, making a product out of it, using it, and finally disposing the product. This take-make-waste approach is extracting resources from the earth which eventually ends up as landfill after use. According to Jonker (2015), the current linear economy is thinking in one value, namely "money". Only, this economy creates secondary effects that show us that our current economy is unsustainable, like exhaustion, pollution, destruction, poverty and inequality.

In response to the Brundland-report (1987), written by the World Commission on Environment and Development (WCED) and named after to the Norwegian chairwoman, business strategies were transformed towards a sustainable, eco-efficient manner. Eco-efficient is related to doing something less bad; using less water, using less energy and using less fossil resources.

Doing less bad isn't good enough, McDonough & Braungart (2002a) stated that current sustainability focus isn't enough to really protect the planet. Therefore they introduced a new strategy of eco-effectiveness. The distinction between both strategies is that eco-efficiency is doing less; eco-effectiveness is doing it completely different. So no more to use less

fossil fuel (eco-efficiency) to no fossil fuels, but switching to renewable sources. By reducing problems with an enormous growth of the world population, it's still not tenable. Eco-effectiveness is fundamentally based on a cyclic approach of a system and is therefore the equivalent to the circular economy. An eco-effectiveness approach pursues a positive footprint for social- and environmental economics, which also applies to the circular economy principles. The principles of the circular economy have deep-rooted origins in a various schools of thoughts such as regenerative design (Lyle, 1994), performance economy (W. R. Stahel, 2010), cradle to cradle (McDonough & Braungart, 2002a), industrial ecology (Jackson & Clift, 1998), biomimicry (Benyus, 2002), green economy (Makower, 2009), blue economy (Pauli, 2010), bio-based economy (Langeveld, Sanders, & Meeusen, 2010), and others.

As can be seen in the previously mentioned definitions of circular economy many definitions of circular economy show the first reflection ripple of circular economy, namely "the way of interpreting". A concise definition of circular economy is: "your outputs become your inputs" (Domenech, 2014). Only, this does not justify the circular economy as a holistic approach.

Since September 2010, the Ellen Mac Arthur Foundation is inspiring the current generation to re-think, re-design and build a positive future and is one of the leading global organizations aiming the acceleration of a transition to the circular economy. Global trends are causing the necessity for the circular economy and the acceleration to it; resource scarcity, volatile price markets, societal unrest, environmental pollution, and rising global temperatures. In a circular economy, growth is decoupled from the use of scarce resources through disruptive technology and business models based on longevity, renewability, reuse, repair, upgrade, refurbishment, capacity sharing, and dematerialization (Accenture, 2014).

According to McDonough & Braungart (2002) in their book 'Cradle to Cradle: remaking the way we make things', the Cradle to Cradle (C2C) concept is a new approach for designing intelligent products, processes and systems taking into account the entire life cycle of the products, optimizing material health, recyclability, renewable energy use, water efficiency and quality, and social responsibility. They made a distinction between the biological nutrients, designed to re-enter the biosphere safely and technical nutrients, which are designed to circulate at high quality without entering the biosphere. MacArthur (2013a) splits both cycles into:

- Biological cycles; in which non-toxic materials are restored into the biosphere while rebuilding natural capital, after being cascaded into different applications;
- Technical cycles; in which products, components and materials are restored into the market at the highest possible quality and for as long as

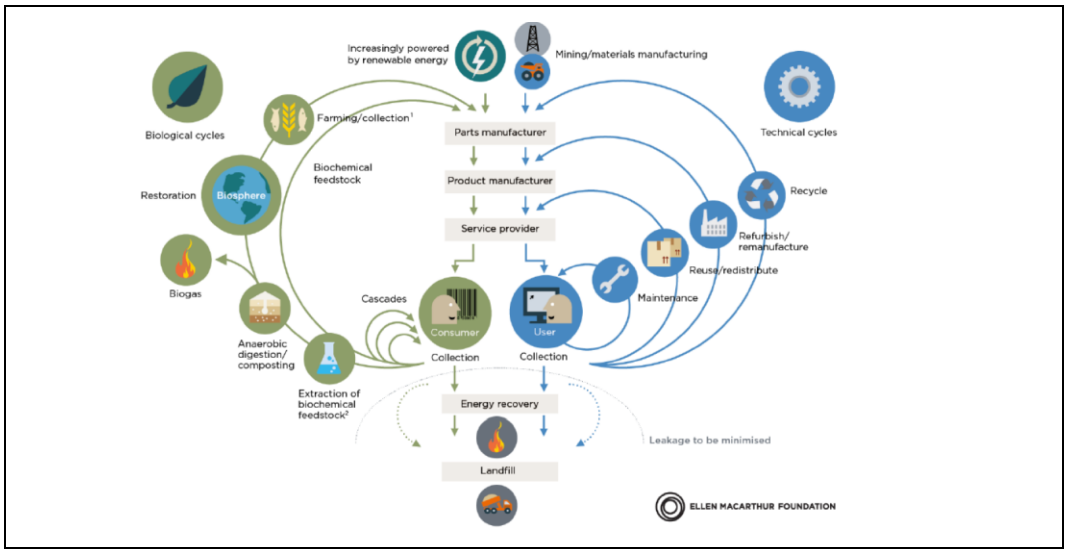
possible, through repair and maintenance, reuse, refurbishment, remanufacture and ultimately recycling.

These different approaches are visualized in Figure 2.2. The central axis shows the linear production process, with mining, production, manufacturing, transportation, consumption and finally waste. In contrast to this linearity, the 'circular' arrows are showing all the potentials of circularity with respect to maintenance, reuse, remanufacture, recycle, and finally minimizing the leakage of waste.

This requires a resource passport, management and exchange of resource-related information, end-of-life systems for flows of resources and products, networks of material exchange and networks of collection (Damen, 2012). A major consequence of taking insights from living systems (networks) is the notion of optimizing systems rather than components, which can also be referred to as 'design to fit' (Ellen MacArthur Foundation, 2013a). According to Braungart and McDonough, it involves a careful management of material flows. Transforming to a circular economy implies a direct impact on our production process and the development of a take-back system and proliferation of product- and business models.

To achieve a more comprehensive explanation of the circular economy, the principles of the holistic approach are preeminent."

Source: Ref. 27 Building Circularity Indicators. An approach for measuring circularity of a building. Jeroen Verberne, 2016



Source: (Ellen MacArthur Foundation & Granta, 2015)

Figure 2.2: Circular economy systems diagram

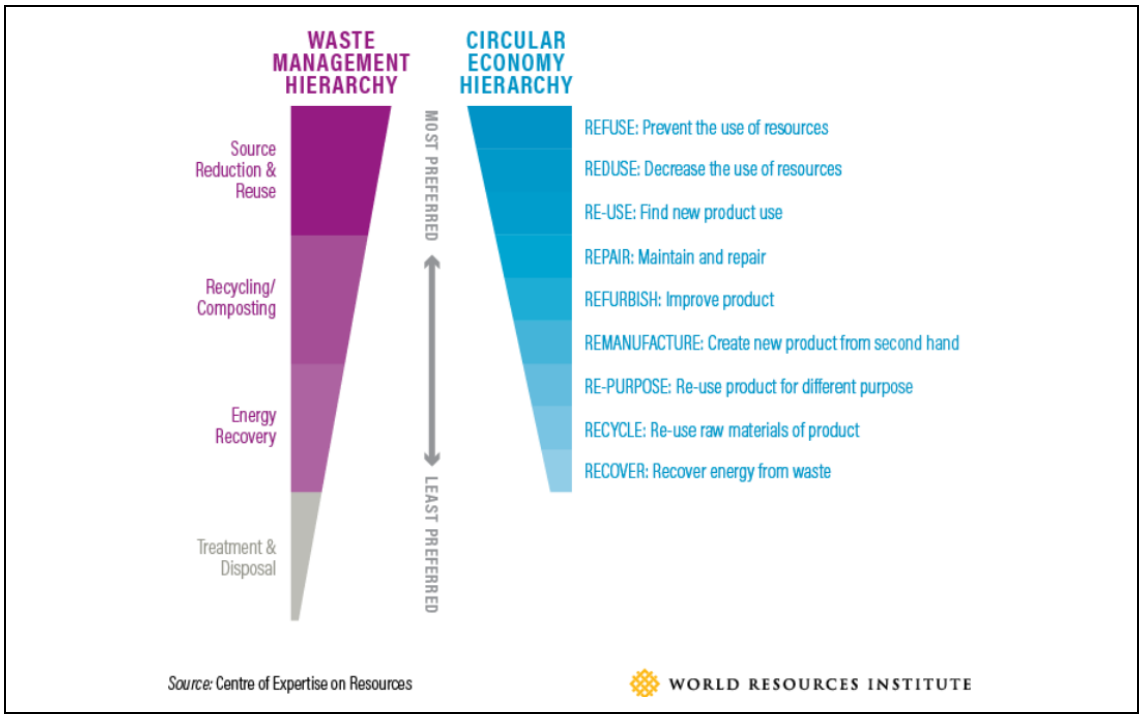


Figure 2.3: Circular economy hierarchy

Source: retrieved from World Resources Institute Blog (Ref. 28)

Houseful Highlights:

There are 114 different definitions of circularity. Some of them are focused on the material resources, but other introduce other concepts as the social dimensions and the environmental benefits. The conclusion is not to add any other definition but have in mind that:

- The circular economy also needs to face with the hierarchy principle (e. g. refuse, by preventing the use of resources; reduce, by decreasing the use of resources; re-use; repair; refurbish; remanufacture; repurpose; recycle; recover)[7].
- The circular economy model goes beyond the material resources
- Circular Economy value should be emphasized in demonstrating how the interests of environmental protection, economic development and social development can be coherent with each other. According to the World Resource Institute, it is need to evaluate employment impact, compare waste reduction against the resource impact of recycling and don't forget soaring levels of consumption[8].

[7] www.wri.org/blog/2019/04/5-ways-unlock-value-circular-economy

[8] www.wri.org/blog/2019/08/here-s-what-could-go-wrong-circular-economy-and-how-keep-it-track

2.1.2 How to measure circularity?

Key points:

- What do we want to measure?
- What a Key Performance Indicators (KPIs) for?
- Indicators for different levels of approach?
    - Indicators that can be used directly for measuring aspects of CE.
    - Indicators that have no direct link with CE but are indirectly related to/affected by CE.
    - Indicators considering different levels: macro, meso, micro;
    - Indicators considering CE strategies
- …

Related references: the specific sources are mentioned below. All of them are listed in the Reference section.

- According to the EASAC indicators report (Ref. 1), "the term 'metric' is also used to refer to parameters used for measurement, comparison or tracking performance. Indicators may well be metrics but tend to be used to quantify a parameter with specific policy or performance significance. The link with such an objective is thus inherent in a metric used as an indicator."

- EASAC indicators report (Ref. 1), "Since resource efficiency and waste reduction are central in a circular economy, indicators on material flows are particularly relevant. The interpretation of material flows nevertheless varies according to the type of material considered (1 tonne of rock from a quarry is very different from 1 tonne of cadmium; 1 tonne of biodegradable waste has a different environmental impact than 1 tonne of electronic waste). Indeed, material flows reported in the recent Raw Materials Scoreboard (EIPRM, 2016) show the extent to which such flows are dominated by construction materials. The use of indicators may also need to be different depending on whether they apply to a business (individual firms), sector (e.g. construction, mining) or whole economy (Bringezu et al., 1997). Flows can also be separated into individual substances (e.g. lead, cadmium), materials (e.g. paper) and products (e.g. cars, computers), further complicating the consideration of indicators.

- A taxonomy of circular economy indicators (Michael Saidani et al., 2018):

  "Dealing with the humongous number of available SDI[9], Bell and Morse (2008) allege that "now we have developed so many indicators that we are having to ask ourselves, what exactly are we measuring"."

  "Circularity indicators are differentiated regarding criteria such as the levels of CE implementation (e.g. micro, meso, macro), the CE loops (maintain,

[9] SDI: Sustainable Development Indicators

reuse, remanufacture, recycle), the performance (intrinsic, impacts), the perspective of circularity (actual, potential) they are taking into account, or their degree of transversality (generic, sector-specific)." (Michael Saidani et al., 2018).

Table 3 – Categories for the proposed taxonomy of C-indicators

Categories *(criteria)*	#1 - **Levels** *(micro, meso, macro)*	#2 - **Loops** *(maintain, reuse/reman, recycle)*	#3 - **Performance** *(intrinsic, impacts)*	#4 - **Perspective** *(actual, potential)*	#5 - **Usages** *(e.g. improvement, benchmarking, communication)*
	#6 - **Transversality** *(generic, sector-specific)*	#7 - **Dimension** *(single, multiple)*	#8 - **Units** *(quantitative, qualitative)*	#9 - **Format** *(e.g. web-based tool, Excel, formulas)*	#10 - **Sources** *(academics, companies, agencies)*

Table 4 – Categorisation of C-indicators according to the micro-, meso- and macro- levels of the CE

Levels	Applications	Example n°1	Example n°2	Example n°3
Macro	Cities, Regions, Nations	Evaluation of CE Development in Cities (ECEDC)	Regional CE Development Index (RCEDI)	National CE Indicator System (NCEIS)
Meso	Businesses, Industrial Symbiosis	Sustainable Circular Index (SCI)	Circular Economic Value (CEV)	Circle Assessment (CA)
Micro	Products, Components, Materials	Circular Economy Indicator Prototype (CEIP)	Product-Level Circularity Metric (PCM)	Material Circularity Indicator (MCI)

- …

Houseful Highlights:

- To monitor the progress towards a circular economy, selected indicators should be able to measure the efficiency with which "material, energy and water resources" are used and considering the environmental and social dimension.
- Need to select an appropriate number of indicators having in mind the feasibility to its use (replicability, calculation tools, etc.).
- Existent indicators can be classified in different levels. Products, components and materials are into the micro level category. The meso level tackle the businesses and the industrial symbiosis, while the macro level category tackle cities, regions and nations.
- Section 2.4 and section 3 delve into KPIs.

2.1.3 Key Words related to circular economy

This section pretends to show simple "headings" or key words to offer a quick overview and a general outlook of what circular economy is about through retrieving some images of relevant publications.

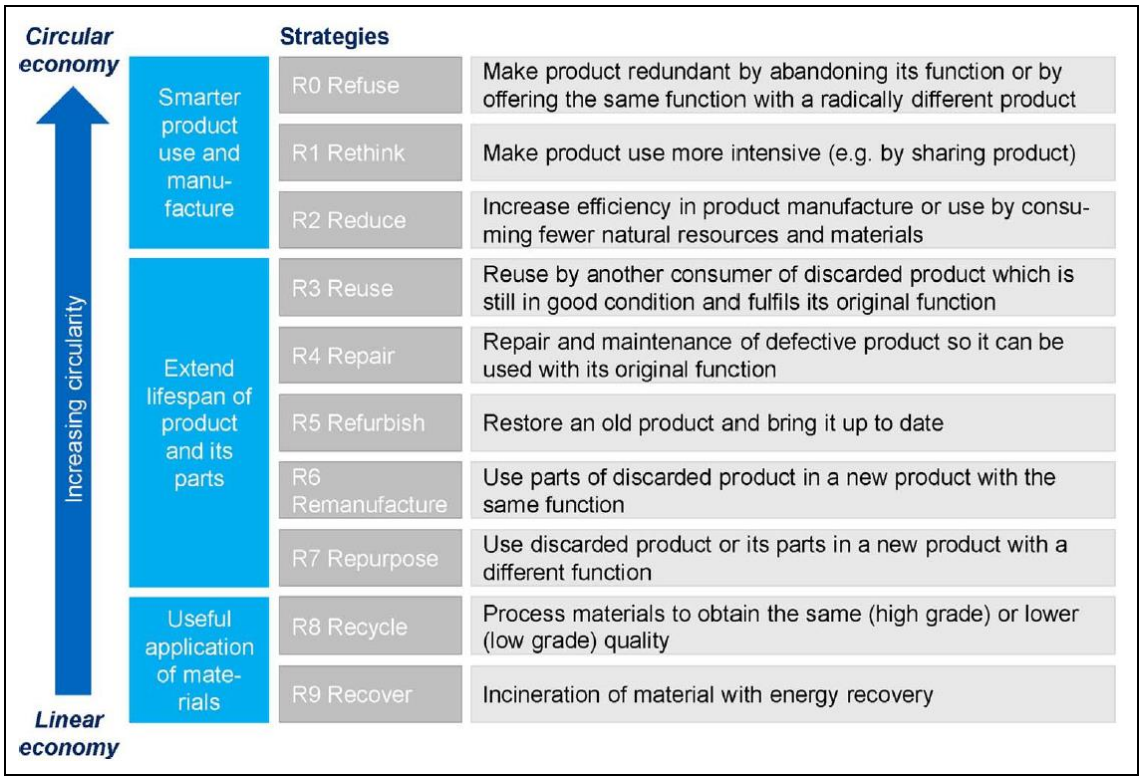


Figure 2.4: The 9R Framework.

Source: (Ref. 5) Julian Kirchherr et al., 2017. Conceptualizing the circular economy: An analysis of 114 definitions

- **Ellen McArthur Foundation – ReSOLVE framework (six action areas for businesses and countries wanting to move towards the circular economy).**

Figure 2.5: The ReSOLVE framework

Source: (Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, Growth Within: A Circular Economy Vision for a Competitive Europe (2015). Based on S. Heck, M. Rogers, P. Carroll, Resource Revolution (2015).

- **Circle economy – DISRUPT framework**

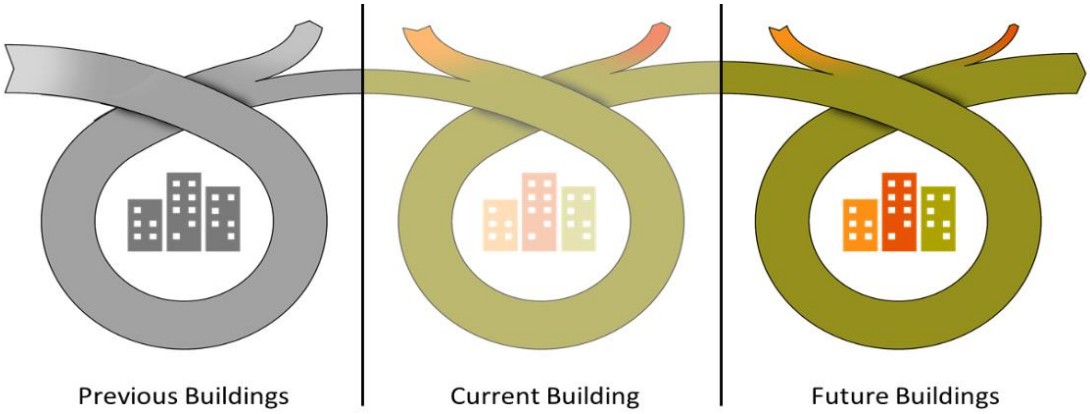
"The circular economy assumes dynamic systems, meaning there is no specific end point, but it is rather a process of transformation. The DISRUPT model describes 7 key elements that give direction to this transformative process, with the aim of slowing the flow of resources, closing the loop and narrowing resources flows, while shifting to regenerative resources and clean energy. The 7 elements describe the full breadth of relevant circular strategies and will be used throughout the report."

Figure 2.6: DISRUPT, 7 key elements of the circular economy.

Source: (Ref. 6) Circle Economy, 2019

- **BAMB - buildings as material banks (H2020 project).**

Circular Building Scenarios



Displacing new products & materials | **Transformation capacity** | **Future reuse potential**

- Using existing building stock: displacing new products & materials
- Optimising life cycle of the building and components: transformation capacity & life cycle co-ordination
- Optimising future use of building stock: reuse potential

Figure 2.7: Circular Building Scenarios according to the BAMB project.

Source: Gilli Hobbs, 2018. (Ref. 3 Circular Building Assessment. A new tool made possible by BAMB)

- **Innovative business models: Accenture**

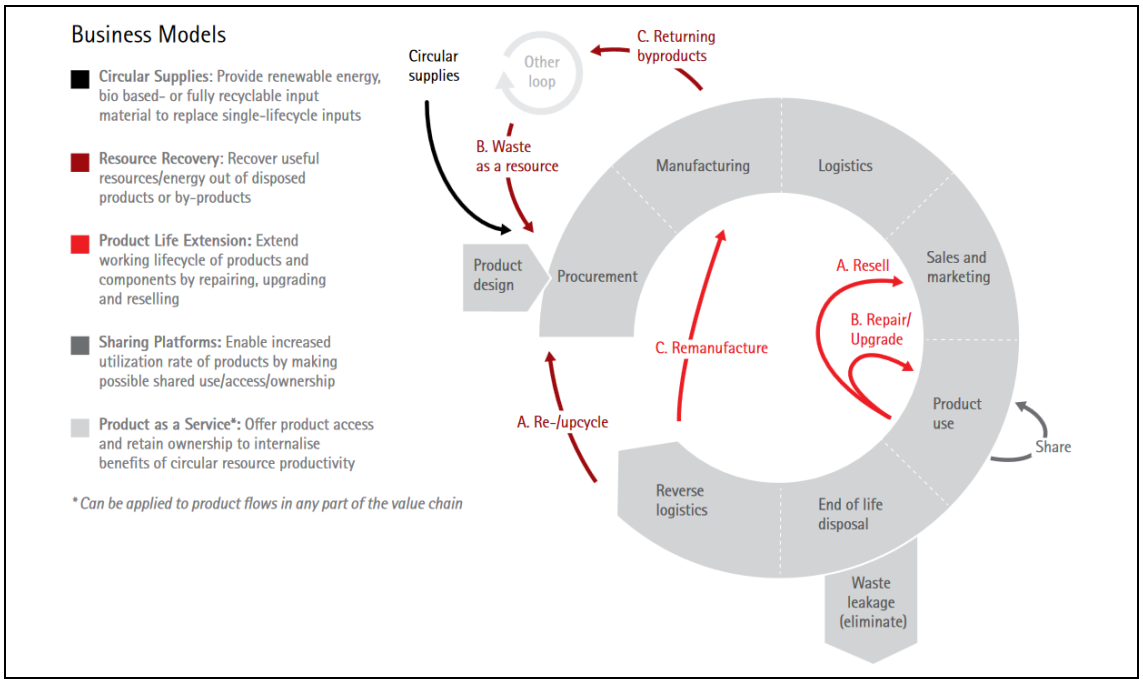
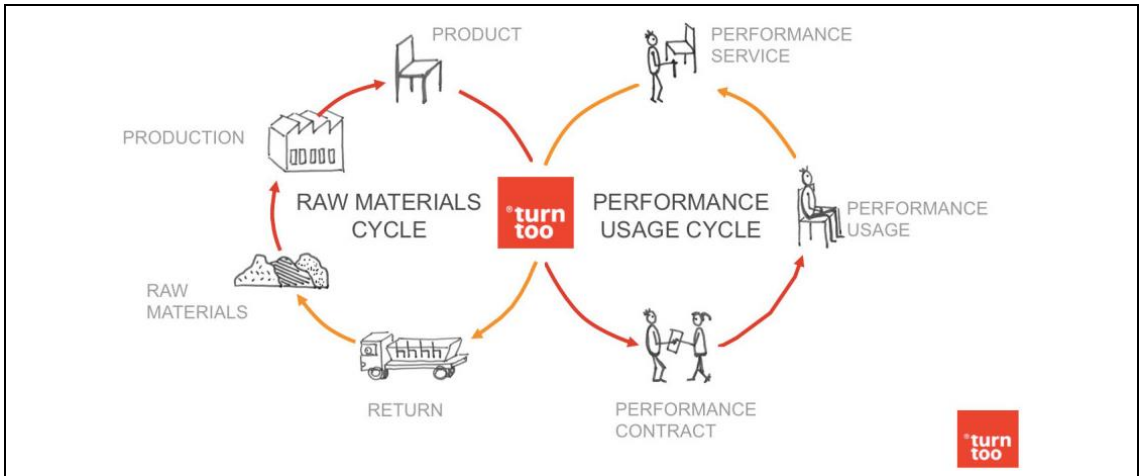


Figure 2.8: The five circular business models

Source: Accenture, 2014 (Ref. 3 Circular Advantage Innovative Business Models and Technologies to Create Value in a World without Limits to Growth).

- **Innovative business: Turntoo - Using instead of consuming**



There is an important distinction to be made between the material loop, which is to be made possible by design for disassembly, recyclable materials, parts harvesting, etc. and the performance cycle which is about prolonging the useful life of a product, through reuse, repair, refurbishment etc.

Figure 2.9: Using instead of consuming by Turntoo.

Source: (

Ref. 7) Design 4 Sustainability platform.

2.2 Overarching themes to be faced by Circular Economy

The starting point for selecting the Key Performance Indicators related to the building circular economy analysis is to face with the main impacts due to the building construction sector.

2.2.1 Limited materials supply and waste generation

- **The problem/opportunity related to materials**

Text Retrieved October 2, 2019, from Raw Materials Scoreboard 2018. European Innovation Partnership on Raw Materials.

"Raw materials are more than ever the lifeblood of the economy.

In the past few years, we have seen an important shift in perspective from 'raw materials are what the objects all around us are made of' to 'raw materials are key enablers of many critical sectors of the economy, such as the automotive, chemical and manufacturing industries' (see Figure 2.10). This shift highlights the need to look beyond what is happening today to take a forwardlooking approach to address future challenges.

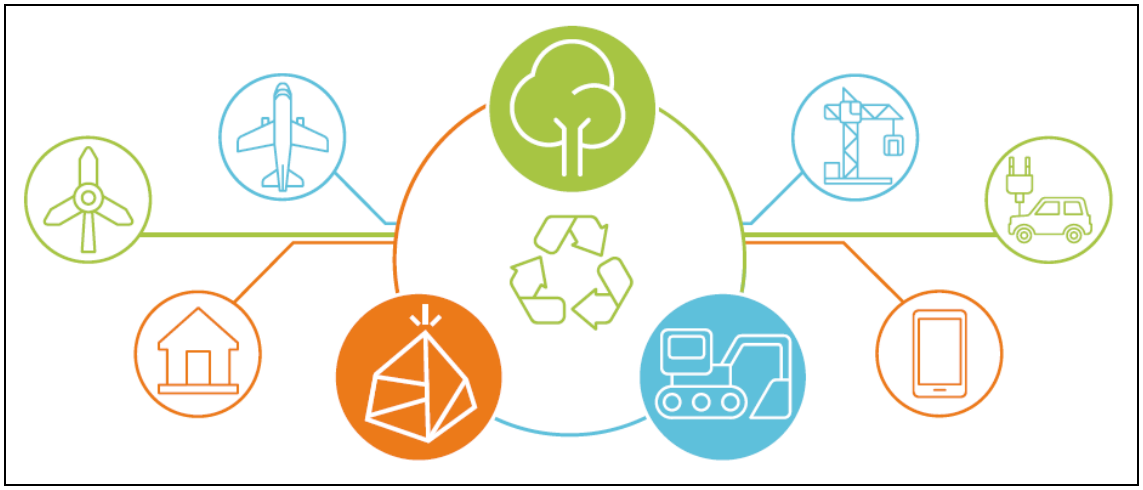


Figure 2.10: Raw Materials — Key enablers of all industrial value chains.

Source: Raw Materials Scoreboard 2018

By 2050, there will be 9.7 billion people in the world. The annual increase in population is equivalent to a country the size of Germany.

Projections indicate that resource use could double between 2010 and 2030. This would mostly be driven by increasing demand in developing regions, where up to 3 billion people will move from low to middle class levels of consumption by 2030. Supply of raw materials will have to match the demand. Consequently, by 2050,

global metals extraction and biomass production will need to increase by at least 50 % and non-metallic minerals production by at least 100 %[10].

Urbanisation will be a key driver of industrial mineral and base metal consumption. More than 50 % of urban areas projected for 2050 have not yet been built. Whereas in 2015 around 54 % of the population lived in cities, in 2050 the share will increase to 66 %[11]. Urbanisation will also increase the competition for land, with possible negative impacts on access to raw materials.

Decarbonisation will also be a key driver in many raw material value chains. The EU is strongly committed to the Paris Agreement to decarbonise the economy and to meet the ambitious target of cutting greenhouse gas emissions to 80-95 % below 1990 levels by 2050. The International Energy Agency's '2°C Scenario' calls for an unprecedented energy transition to decarbonise the power sector by 2060[12]. This could be achieved particularly through the large deployment of renewable energy sources and through energy efficiency in general. EU industries, particularly energy-intensive industries that process raw materials, are also on their way to decarbonisation.

The European Commission adopted a renewed EU industrial policy strategy[13] in September 2017. This acknowledges that embracing technological breakthroughs while making the transition to a low carbon and circular economy by 2050 is a major challenge for EU industry. This transition relies on the EU's raw materials policy[14] to help ensure a secure, sustainable and affordable supply of raw materials for the EU's manufacturing industry. This will be supported through, for example, the circular economy action plan, fostering domestic production as part of the responsible sourcing mix, due diligence policy and the 'single market for green products' initiative. The EU is also committed to implementing the 2030 Agenda for Sustainable Development, including the Sustainable Development Goals (SDGs), and to developing cooperation with partner countries in this respect. The raw materials sector, being global by definition, is and will be a key contributor to all 17 SDGs[15]."

<u>The construction and use of buildings in the EU account for about:</u>

- 50% of extracted material resources[16].

- **The problem/opportunity related to waste generation:**

[10] http://www.resourcepanel.org/reports/assessing-global-resource-use
[11] https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf
[12] https://www.iea.org/publications/insights/insightpublications/Renewable_Energy_for_Industry.pdf.
[13] COM (2017) 479 final.
[14] See: https://ec.europa.eu/growth/sectors/raw-materials/policy-strategy_en
[15] UN General Assembly. Transforming our world: the 2030 Agenda for Sustainable Development. New York: United Nations. 2015.
[16] COM (2011) 571 final, Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the regions, Roadmap to a Resource Efficient Europe, Brussels.

Text Retrieved October 2, 2019, from:

https://ec.europa.eu/environment/waste/index.htm

"In Europe, we currently use 16 tonnes of material per person per year, of which 6 tonnes become waste. Although the management of that waste continues to improve in the EU, the European economy currently still loses a significant amount of potential 'secondary raw materials' such as metals, wood, glass, paper, plastics present waste streams. In 2010, total waste production in the EU amounted to 2,5 billion tons. From this total only a limited (albeit increasing) share (36%) was recycled, with the rest was landfilled or burned, of which some 600 million tons could be recycled or reused.

Just in terms of household waste alone, each person in Europe is currently producing, on average, half of tonne of such waste. Only 40 % of it is reused or recycled and, in some countries, more than 80% still goes to landfill (source: Environmental Data Centre on Waste, Eurostat).

Turning waste into a resource is one key to a circular economy. The objectives and targets set in European legislation have been key drivers to improve waste management, stimulate innovation in recycling, limit the use of landfilling, and create incentives to change consumer behaviour. If we re-manufacture, reuse and recycle, and if one industry's waste becomes another's raw material, we can move to a more circular economy where waste is eliminated and resources are used in an efficient and sustainable way.

Improved waste management also helps to reduce health and environmental problems, reduce greenhouse gas emissions (directly by cutting emissions from landfills and indirectly by recycling materials which would otherwise be extracted and processed), and avoid negative impacts at local level such as landscape deterioration due to landfilling, local water and air pollution, as well as littering.

The European Union's approach to waste management is based on the "waste hierarchy" which sets the following priority order when shaping waste policy and managing waste at the operational level: prevention, (preparing for) reuse, recycling, recovery and, as the least preferred option, disposal (which includes landfilling and incineration without energy recovery)."

The construction and use of buildings in the EU account for about:

- 33,5 % of construction and demolition waste (CDW)[17].

Source: Extract from Raw Materials Scoreboard 2018. European Innovation Partnership on Raw Materials

- *"Construction and demolition is the biggest source of waste, contributing to around a third of all waste in the EU (in mass).*
- *Most construction and demolition waste can be easily recovered through recycling or backfilling.*

[17] SWD (2018) 17 final

Construction and demolition is the single biggest source of waste in mass in Europe: it accounted for 33.5% of all waste in the EU in 2014 (871 million tonnes)[18]. Construction and demolition waste (CDW) consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents and excavated soil, many of which can be recycled[19]. The most (economically and environmentally) valuable fractions (e.g. metals, plastics, glass) represent only a small percentage of all CDW[20]. High re-use or recovery rates of such materials could lead to significant sustainability gains, but these would not be reflected in the overall recovery statistics, which are currently dominated by the largest material fractions (in mass). Moreover, the increase of re-use in the construction and demolition sector could have positive effects with regards to both job creation and environmental impacts[21].

CDW arises from activities such as the construction, renovation, total or partial demolition of buildings and civil infrastructure, and road construction and maintenance.

Important factors for feeding these materials back into the economy are:

- *the proper design of building materials and constructions;*
- *the selective demolition of constructions;*
- *the sorting of recoverable and hazardous fractions from demolition waste;*
- *and quality assurance schemes to build up trust in recycled materials[22]*

CDW is subject to a mandatory recovery target (70% by 2020) under the Waste Framework Directive[23]. Recovery of CDW can also include backfilling operations. 'Backfilling' means any recovery operation where suitable non-hazardous waste is used for purposes of reclamation in excavated areas or for engineering purposes in landscaping. Waste used for backfilling must substitute non-waste materials, be suitable for the aforementioned purposes, and be limited to the amount strictly necessary to achieve those purposes[24]."

2.2.2 Environmental impacts related to energy production/consumption

Text Retrieved October 2, 2019, from:

[18] SWD (2018) 17 final. Commission Staff Working Document. 'Measuring progress toward circular economy in the European Union — Key indicators for a monitoring framework'.

[19] DG Environment, Resource-efficient use of mixed wastes, http://ec.europa.eu/environment/waste/studies/mixed_waste.htm.

[20] SWD (2018) 17 final. Commission Staff Working Document. 'Measuring progress toward circular economy in the European Union — Key indicators for a monitoring framework'

[21] Rreuse, 2017, 'Austrian social enterprises develop a business model for re-use of building materials', http://www.rreuse.org/austrian-social-enterprises-develop-a-business-model-for-re-use-of-building-materials/.

[22] SWD (2018) 17 final. Commission Staff Working Document. 'Measuring progress toward circular economy in the European Union — Key indicators for a monitoring framework'.

[23] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3)

[24] Directive of the European Parliament and of the Council amending Directive 2008/98/EC on Waste, PE 11 2018 REV 2, 30.05.02017.

Source: https://ec.europa.eu/environment/integration/energy/index_en.htm

"Energy/Climate and environmental policies are inextricably linked. All energy production and consumption has environmental impacts. Whilst it is often tempting to overlook the environment during difficult economic times, the challenges of producing and using energy resources sustainably and protecting our natural environment equally represent an opportunity to pursue sustainable economic growth, while contributing to climate change mitigation and adaptation.

In many regards energy, climate and environmental objectives go hand in hand, such as:

- *energy efficiency and reducing energy use: saving energy can help avoid impacts associated with extractive industries and with energy generation, transformation, distribution and consumption in general. It can help reducing GHG emissions, air pollution, impacts to surface and ground waters, habitat fragmentation and biodiversity disturbance through infrastructure and land use, etc. The EU has put forward several measures to improve efficiency at all stages of the energy chain and it is aiming for a 20% cut in Europe's annual primary energy consumption by 2020 and has proposed more ambitious goals for 2030.*
- *measures to increase the share of sustainable renewable energy sources in the energy mix can lower overall environmental and climatic pressures compared to other forms of energy. Such measures can also contribute to improved resource efficiency where they result in a more efficient utilisation of non-recyclable waste streams.*
- *Measures aiming at promoting circular economy and using resources in a more efficient way also contribute to reducing energy demand: this is in particular the case when products are re-used, materials recycled, when all production and consumption chains are organised in a more efficient way (read more on circular economy)."*

The construction and use of buildings in the EU account for about:

- 40% of gross final energy consumption[25].
- 35% of greenhouse gases emissions.

2.2.3 Water scarcity

Text Retrieved October 30, 2019, from:

https://ec.europa.eu/environment/water/quantity/scarcity_en.htm

"While Europe is by large considered as having adequate water resources, water scarcity and drought is an increasingly frequent and widespread phenomenon in the European Union. The long-term imbalance resulting from water demand exceeding available water resources is no longer uncommon.

[25] COM (2007) 860

It was estimated that by 2007, at least 11 % of Europe's population and 17 % of its territory had been affected by water scarcity, putting the cost of droughts in Europe over the past thirty years at EUR 100 billion. The Commission expects further deterioration of the water situation in Europe if temperatures keep rising as a result of climate change. Water is no longer the problem of a few regions, but now concerns all 500 million Europeans.

The main overall objective of EU water policy is to ensure access to good quality water in sufficient quantity for all Europeans, and to ensure the good status of all water bodies across Europe. Therefore, policies and actions are set up in order to prevent and to mitigate water scarcity and drought situations, with the priority to move towards a water-efficient and water-saving economy."

The construction and use of buildings in the EU account for about:

- 30% of water consumption[26]

2.2.4 Air quality

Text Retrieved October 30, 2019, from:

https://ec.europa.eu/environment/air/index_en.htm

"Clean air is essential to our health and to the environment. But since the industrial revolution, the quality of the air we breathe has deteriorated considerably - mainly as a result of human activities. Rising industrial and energy production, the burning of fossil fuels and biomass, as well as the dramatic rise in traffic on our roads all contribute to air pollution in our towns and cities which, in turn, can lead to serious problems for both health and the environment.

The human toll for poor air quality is worse than for road traffic accidents, making it the number one environmental cause of premature death in Europe, with over 390 000 premature deaths every year. It also impacts on quality of life by causing or exacerbating asthma and respiratory problems. Air pollution causes lost working days, and high healthcare costs, with vulnerable groups such as children, asthmatics and the elderly the worst affected. It damages ecosystems through excess nitrogen pollution (eutrophication) and acid rain."

2.2.5 Economic inability to keep home adequately warm

Ref. 43 Energy poverty and vulnerable consumers in the energy sector across the EU: analysis of policies and measures. INSIGHT_E project. Steve Pye, Audrey Dobbins et a., 2015

"Energy poverty, often defined as a situation where individuals or households are not able to adequately heat or provide other required energy services in their homes at affordable cost, is a problem across many Member States. This is due to rising energy prices, recessionary impacts on national and regional economies, and poor energy efficient homes. The EU Survey on Income and Living Conditions (EU SILC) estimates

[26] COM (2007) 414

that 54 million European citizens (10.8% of the EU population) were unable to keep their home adequately warm in 2012, with similar numbers being reported with regard to the late payment of utility bills or presence of poor housing conditions. Based on these proxy indicators, a particularly pervasive problem is highlighted in Central Eastern European and Southern Europe Member States."

2.3 Boosting the circular economy

2.3.1 The European Circular Economy Package

The text below is retrieved from the Ref. 19 European Commission, COM (2019) 190 final, report on the implementation of the Circular Economy Action Plan).

> *"In December 2015, the Commission adopted a Circular Economy Action Plan[27] to give a new boost to jobs, growth and investment and to develop a carbon neutral, resource-efficient and competitive economy. The 54 actions under the action plan have now been completed or are being implemented, even if work on some will continue beyond 2019.*
>
> *The EU Monitoring Framework for the Circular Economy[28] shows that the transition has helped put the EU back on a path of job creation. In 2016, sectors relevant to the circular economy employed more than four million workers, a 6% increase compared to 2012. Additional jobs are bound to be created in the coming years in order to meet the expected demand generated by fully functioning markets for secondary raw materials[29].*
>
> *Circularity has also opened up new business opportunities, given rise to new business models and developed new markets, domestically and outside the EU. In 2016, circular activities such as repair, reuse or recycling generated almost €147 billion in value added while standing for around €17.5 billion worth of investments.*
>
> *In Europe, recycling of municipal waste during the period 2008-2016 has increased and the contribution of recycled materials to the overall materials demand shows continuous improvement. However, on average, recycled materials only meet less than 12 % of the EU demand for materials. This is echoed by a recent stakeholder report suggesting that full circularity would apply to only 9%[30] of the world economy, leaving vast areas for improvement."*

The mentioned report synthesizes accurately the current context on the circular economy package, explaining how the circular economy in Europe is built on 5 key topics. It is important to add that the construction sector has impact on all of them.

1. **Circular designs and production processes.** Where Buildings and Construction Products is one of the eight priority product categories for the circular economy[31]. (Ref. 21).
   - …
2. **Empowering consumers**

[27] COM (2015) 614

[28] COM (2018) 29 final

[29] European Commission, *Impacts of circular economy policies on the labour market*, April 2018

[30] Circle Economy, *The Circularity Gap Report,* January 2018

[31] SWD (2019) 91

- Strategic approach to increase the effectiveness of Ecolabels, development of Product Environmental Footprint (PEF) and Environmental product declarations (EPD).
- New and revised EU Green Public Procurement criteria including circular economy aspects. (Table 2.1)

3. **Turning waste into resources.** The main instrument to reach this goal is the revised waste legislative framework. Regarding the building and construction products it is important to highlight the next:
   - Simplification and harmonisation of definitions and calculation methods and clarified legal status for recycled materials and by-products;
   - Reinforced rules and new obligations on separate collection (bio-waste, textiles and hazardous waste produced by households, construction and demolition waste).
   - …
4. **Closing loops of recovered materials** for boosting the use of secondary raw materials (SRMs).

5. **Specific strategy for plastics in a circular economy**

CIRCULAR PROCUREMENT MODELS		
System Level	Supplier Level	Product
Product service system • Public Private Partnership • Cooperation with other organisations on sharing and reuse • Rent/Lease • Supplier take-back systems including reuse, recycling, refurbishment and remanufacturing	Product service system • Supplier take-back systems • Design to disassembly • Reparability of standard products • External reuse/sale of products • Internal reuse of products	Product service system • Materials in the product can be identified • Products can be disassembled after use • Recyclable materials • Resource efficiency and total cost of ownership • Recycled materials

Table 2.1: Circular Procurement Models

Source: Adapted from Public procurement for a circular economy. Good practice and guidance, 2017 (Ref. 22).

Circular Public Procurement (CPP) is an example of the European Union's efforts in adapting existing instruments focused on environmental protection towards the circular economy, considering that it is the way to overcome the current patterns of unsustainable production and consumption without compromising economic growth.

For example, as cited in the article Embedding sustainable thinking in public procurement could support circular economy (Ref. 23) "…circular business models and approaches to managing materials could potentially be driven by public procurement. At present, public procurement accounts for an average 14% of gross

domestic product in the EU, and so offers a sizeable opportunity to progress the transition to CE in Europe."

The same source categorizes the Circular Public Procurement (CPP) approaches in four areas according to 18 European cases studies that represented different sectors, markets, and business models (including construction of buildings and infrastructure, water, sewage and waste management, vehicles and logistics, food and catering, furniture and textiles). The mentioned four areas are[32]:

> *"1. procurement of improved products or services by adding GPP-based 'circular criteria' to the tender competition, such as for recyclability and reuse of materials;*
>
> *2. procurement of services and use of new business concepts that promote CE and efficient material cycles, such as product-service systems, leasing concepts, shared use, buy-per-use, and buying and selling back — for example furniture leasing or car hire;*
>
> *3. procurement of new and innovative products, services, and materials promoting CE, to stimulate innovation and create new associated business and markets — products of better quality in terms of recyclability, recycled materials, lifespan, disassembly, and so on;*
>
> *4. procurement that promotes industrial symbiosis and circular ecosystems, which can provide efficient platforms for supporting closed loops and creating networks in which the waste from one stakeholder can be used as a raw material for another (for example, buses running on locally produced bioenergy)."*
>
> *Source:* (Ref. 23)

The European Circular Economy Web page[33] includes key documents and links to deep into the Implementation of the Circular Economy Action Plan and complementary instruments as the European Circular Economy Stakeholder Platform, as a place to exchange, interact and make circular economy happen faster to the benefit of all.

2.4 Main methodologies and KPIs references related to circular economy

As mentioned before in the *section 2.1.2 How to measure circularity?*, an indicator allows to quantify a parameter with an specific objective (policy or intended performance).

[32] Text extracted from Science for Environment Policy. 31 January 2019 Issue 520. Embedding sustainable thinking in public procurement could support circular economy, based on the study "Exploiting the Potential of Public Procurement: Opportunities for Circular Economy. Journal of Industrial Ecology (Alhola et al, 2018)."

[33] https://ec.europa.eu/environment/circular-economy/index_en.htm

The following sections compile the main frameworks for the metric of the circular economy. Additionally, section 3 includes meaningful references to the development of the circular economy focused on the construction sector, which are developed considering the general reference frameworks.

2.4.1 European Commission - Measuring progress towards CE in the EU

The report on the implementation of the Circular Economy Action Plan published by the European Commission[34], (Ref. 19), says the next:

> *"The EU Monitoring Framework for the Circular Economy presented by the Commission in 2018 includes 10 key indicators covering each phase of the lifecycle of products as well as competitiveness aspects.*
>
> *All indicators are regularly updated and available on a dedicated website[35]. Some Member States have developed additional national circular economy indicators, thus complementing the overview provided by the EU framework. The European Parliament[36], the Council[37] and the European Economic Social Committee[38] have also highlighted the role played by other indicators in capturing missing aspects of the circular economy, such as evaluating material flows in industrial symbiosis and accounting for natural capital."*

Next references show the progress done on the measuring towards Circular Economy in the European Union as well as the selected indicators and the sources to find the methodology that supports them.

(Ref. 8) **Communication from the Commission (…) on a monitoring framework for the circular economy. COM/2018/029 final**

This document shows the context of the current situation in the EU and list the indicators taken into account.

"In the circular economy action plan, circular economy is explained as an economy 'where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised'.

[…] Also, the European Parliament has called upon the Commission to develop indicators on resource efficiency to track progress towards the circular economy.

[…] The circular economy monitoring framework draws upon and complements the existing Resource Efficiency Scoreboard and Raw Materials Scoreboard, which were developed in recent years by the Commission. The framework is presented on a website[39] where all the indicators are available and will be kept up to date.

[34] COM (2019) 190 final

[35] https://ec.europa.eu/eurostat/web/circular-economy

[36] Question for oral answer O-000087/2018

[37] 10447/18 – Council Conclusions Delivering on the EU Circular Economy Action Plan

[38] NAT/722-EESC-2018-00464

[39] http://ec.europa.eu/eurostat/web/circular-economy.

[…] The monitoring framework has a set of ten indicators (see Table 1) grouped into four stages and aspects of the circular economy: (1) production and consumption, (2) waste management, (3) secondary raw materials and (4) competitiveness and innovation." See Figure 2.11 and Table 2.2. http://ec.europa.eu/environment/circular-economy/pdf/monitoring-framework.pdf
(Ref. 9) **Measuring progress towards circular economy in the European Union - Key indicators for a monitoring framework. SWD (2018) 17 final** The set of ten indicators are listed on p.6 (Table 1) and discussed in detail. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018SC0017&from=en https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2018:17:FIN
(Ref. 10) **Circular Economy monitoring** Brief of the previous documents and links to related statistical data. http://rmis.jrc.ec.europa.eu/?page=circular-economy-monitoring
(Ref. 11) **Material flows in the circular economy - visual overview. The Raw Materials Scoreboard** *"The RM Scoreboard presents the best available data and indicators on the main challenges of raw materials production in the EU, along the entire raw materials value chain. The EC released the first edition of the RM Scoreboard in July 2016, and biannual updates are foreseen."* http://rmis.jrc.ec.europa.eu/?page=scoreboard#/ind15

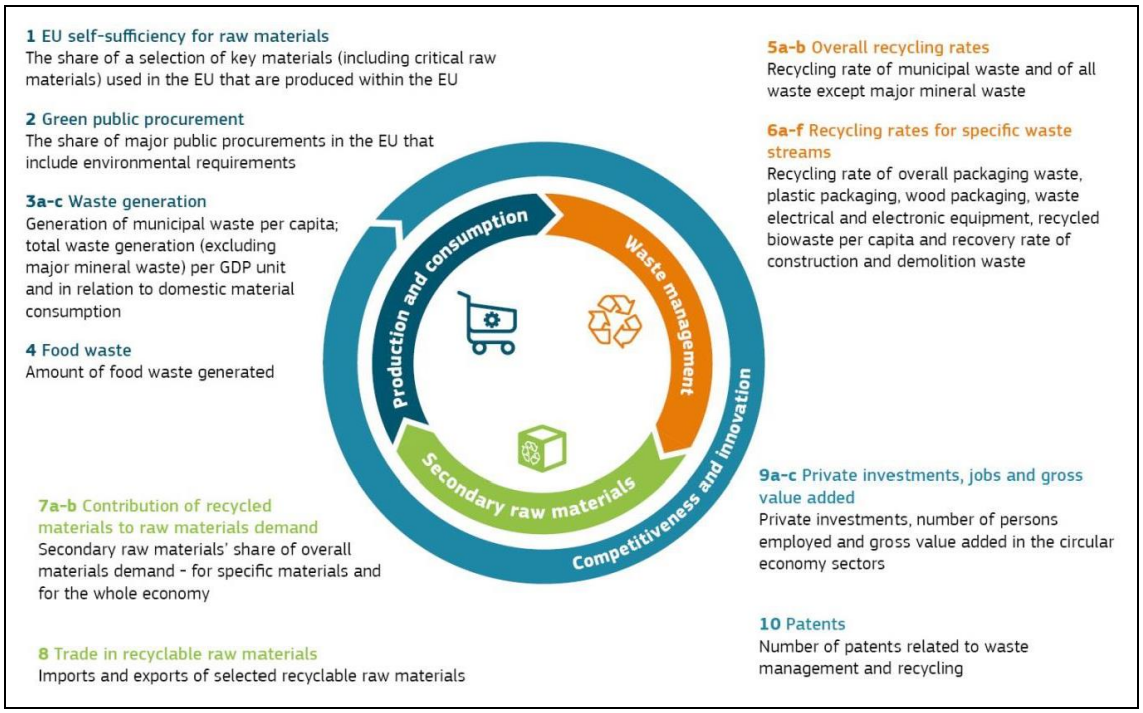


Figure 2.11: Circular economy monitoring framework

Source: COM/2018/029 final (Ref. 8)

No	Name	Relevance	EU levers (examples)
Production and consumption			
1	EU self-sufficiency for raw materials	The circular economy should help to address the supply risks for raw materials, in particular critical raw materials.	Raw Materials Initiative; Resource Efficiency Roadmap
2	Green public procurement*	Public procurement accounts for a large share of consumption and can drive the circular economy.	Public Procurement Strategy; EU support schemes and voluntary criteria for green public procurement
3a-c	Waste generation	In a circular economy waste generation is minimised.	Waste Framework Directive; directives on specific waste streams; Strategy for Plastics
4	Food waste*	Discarding food has negative environmental, climate and economic impacts.	General Food Law Regulation; Waste Framework Directive; various initiatives (e.g. Platform on Food Losses and Food Waste)
Waste management			
5a-b	Overall recycling rates	Increasing recycling is part of the transition to a circular economy.	Waste Framework Directive
6a-f	Recycling rates for specific waste streams	This reflects the progress in recycling key waste streams.	Waste Framework Directive; Landfill Directive; directives on specific waste streams
Secondary raw materials			
7a-b	Contribution of recycled materials to raw materials demand	In a circular economy, secondary raw materials are commonly used to make new products.	Waste Framework Directive; Eco-design Directive; EU Ecolabel; REACH; initiative on the interface between chemicals, products and waste policies; Strategy for Plastics; quality standards for secondary raw materials
8	Trade in recyclable raw materials	Trade in recyclables reflects the importance of the internal market and global participation in the circular economy.	Internal Market policy; Waste Shipment Regulation; Trade policy
Competitiveness and innovation			
9a-c	Private investments, jobs and gross value added	This reflects the contribution of the circular economy to the creation of jobs and growth.	Investment Plan for Europe; Structural and Investment Funds; InnovFin; Circular Economy Finance Support Platform; Sustainable Finance Strategy; Green Employment Initiative; New Skills Agenda for Europe; Internal Market policy
10	Patents	Innovative technologies related to the circular economy boost the EU's global competitiveness.	Horizon 2020

* Indicators under development

Table 2.2: Circular economy monitoring framework

Source: COM/2018/029 final (Ref. 8)

Area		*Indicator*
Production and consumption	1	**1. EU self-sufficiency for raw materials**
	2	**2. Green public procurement**
	3	**3. Waste generation**
		3.a • Generation of municipal waste (per capita)
		3.b • Generation of waste excluding major mineral wastes, per GDP unit
		3.c • Generation of waste excluding major mineral wastes, per domestic material consumption
	4	**4. Food waste**
Waste management	5	**5. Recycling rates**
		5.a • Recycling rate of municipal waste
		5.b • Recycling rate of all waste excluding major mineral waste
	6	**6. Recycling for specific waste streams**
		6.a • Recycling rate for overall packaging
		6.b • Recycling rate of plastic packaging
		6.c • Recycling rate of wooden packaging
		6.d • Recycling rate of e-waste
		6.e • Recycling of bio-waste
		6.f • Recovery rate of construction and demolition waste
Secondary raw materials	7	**Contribution of recycled materials to raw materials demand**
		7.a • End-of-life recycling input rates for raw materials
		7.b • Circular material use rate
	8	**Trade in recyclable raw materials**
Competitiveness and innovation	9	**Private investment, jobs and gross value added related to CE sectors**
		9.a • Gross investment in tangible goods
		9.b • Number of persons employed
		9.c • Value added at factor cost
	10	**Number of patents related to recycling and secondary raw materials**

Table 2.3: Relevant indicators for the each of the 4 areas covered by the European circular economy monitoring framework

Source: SWD (2018) 17 final (Ref. 9)

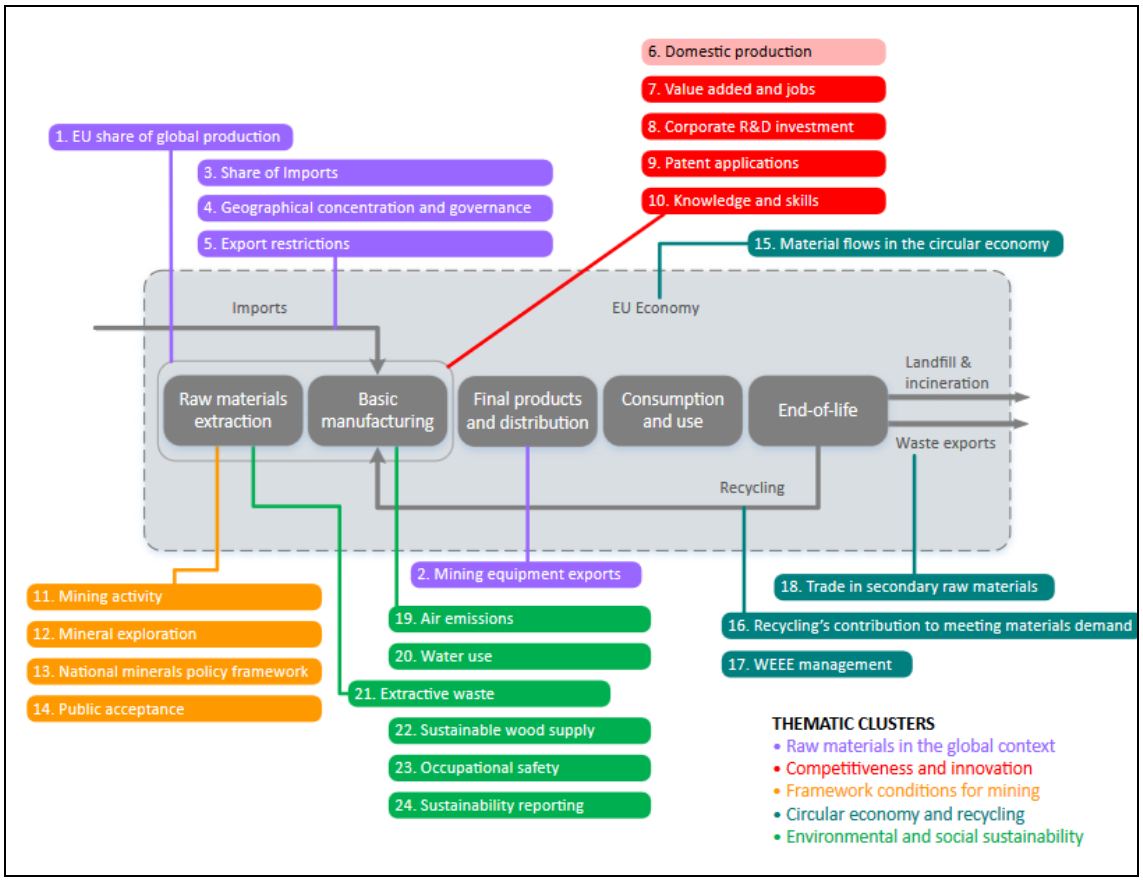


Figure 2.12: The Raw Materials Scoreboard 2016. Thematic clusters

Source: rmis.jrc.ec.europa.eu (Ref. 11)

- **Houseful highlights**

Main objective:	To unify criteria and align with EU strategies. From macro to micro → From macro economy to the construction sector → From de construction sector to the buildings
Action:	a) Select those indicators that can have a potential relation to building circularity. b) Linking indicators and calculation methodology whenever possible. c) Providing ideas on how the indicators can be measured (e.g. Recycling of biowaste per capita → Proximity to biowaste collection / Availability of biowaste digestion technologies).

2.4.2 Eco-innovation Action Plan. Circular economy indicators

(Ref. 12) **Circular Economy Indicators**

https://ec.europa.eu/environment/ecoap/indicators/circular-economy-indicators_en

"The basic concept of a circular economy depicts a production and consumption system that relies on the recycling, re-use, repair, remanufacturing, sharing of products, changing the consumption patterns and new business models and systems.

There is no indicator that can be a single measurement for the Circular Economy. However a number of existing indicators can help to measure performance in several areas that directly or indirectly contribute to the Circular Economy development. They can be grouped into the following groups:

- *Sustainable resource management*

This set of indicators examines the performance of the EU Member States in transforming their economies toward circularity by lowering resource demands, thereby increasing resource security and lowering pressures on the environment domestically and abroad.

- *Societal behaviour*

This set of indicators reflect citizen awareness, engagement and participation in the circular economy. Citizen engagement, behaviour change and social norms are integral to the success of a circular economy transition. This means that people participate in new forms of consumption (e.g. sharing, product-service systems, willingness to pay more for durability), re-use (requiring changed mindsets regarding repair and refurbishment), and disposal (separating waste streams and bringing ""waste"" to remanufacturing/recycling/sorting sites).

- *Business operations*

This set of indicators depicts eco-innovation activities toward changing and adapting business models according to the principles of a circular economy. Businesses are the engine behind the circular economy transition. They foster circularity across the life-cycle of material use, beginning with how and what materials are sourced (quality, environmental and health standards). The design stage is particularly crucial to enabling re-use / re-manufacturing / recycling and raising the durability of goods for keeping within the economy longer. Remanufacturing and recycling are key business operations critical to scaling up the circular economy."

- Houseful highlights

Main objective:	To unify criteria and align with EU strategies. From macro to micro → From macro economy to the construction sector → From de construction sector to the buildings
Action:	a) Select those indicators that can have a potential relation to building circularity. b) Linking indicators and calculation methodology whenever possible. c) Providing ideas on how the indicators can be measured

2.4.3 Ellen MacArthur Foundation

(Ref. 13) **Circularity indicators for providing a methodology and tools to assess how well a product or company perform in the circular economy**

http://www.ellenmacarthurfoundation.org/circularity-indicators/

- (Ref. 14) **The Material Circularity Indicator (hereafter, MCI)[40].**

"The Material Circularity Indicator (MCI) developed focuses on the restoration of material flows at product and company levels and is based on the following four principles:

i) using feedstock from reused or recycled sources

ii) reusing components or recycling materials after the use of the product

iii) keeping products in use longer (e.g., by reuse/redistribution)

iv) making more intensive use of products (e.g. via service or performance models)

While the MCI provides an indication of how much a product's materials circulate, it neither takes into account what these materials are, nor does it provide information on other impacts of the product.

- *Complementary risk indicators giving an indication on the urgency of implementing circular practices. These are related to the drivers for change from the current linear model. These include, for example, measures of material **scarcity** (which has a substantial impact on the value of recovering the materials) and a measure of **toxicity** (which impacts the risks and costs of manufacture reverse logistics and public safety liabilities).*
- *Complementary impact indicators giving an indication of some of the benefits of circular models. They include a measure of the energy and water impacts of a given setup."*

- Houseful highlights

Main objective:	Use of existent agreed and harmonised indicators. The MCI (material circularity indicator) are already stablished for material resources. Try to expand the MCI to the water, energy resources, GHE, and social issues.
Action:	a) Search references on MCI applicated to the building sector (e.g. Madaster MCI). b) Evaluate the viability of MCI calculation methodology for buildings and extension to the water and energy resources. c) Take inspiration from existing strategy and indicator frameworks (including BREEAM, other standards amongst which LEED, DGNB, Cradle to Cradle.

[40] Circularity indicators. An Approach to Measuring Circularity (Methodology). Ellen Macarthur Foundation and Granta Design, 2015.

2.4.4 C2C Cradle to Cradle Products Innovation Institute

https://www.c2ccertified.org/resources/collection-page/cradle-to-cradle-certified-resources-public

The Cradle to Cradle® product standard is divided in the next categories: Material Health, Material reutilization, Renewable Energy and Carbon Management, Water Stewardship and Social Fairness.

One of the Cradle to Cradle® principles is to eliminate the concept of waste, that is tackled in the category Material reutilization.

According (Ref. 16)[41]:

- Eliminate the Concept of 'Waste': *"A significant focus of Cradle to Cradle® as a product design framework is to promote the creation of an optimized materials economy that eliminates the concept of "waste." This category of the program is intended to create incentives for industry to eliminate the concept of "waste" by designing products with materials that may be perpetually cycled to retain their value."*

- *"**Material reutilization** is a key component of Cradle to Cradle design is the concept of technical nutrients and biological nutrients flowing perpetually in their respective metabolisms. Products are evaluated for their nutrient potential and nutrient actualization, as well as the role the manufacturer plays in material/nutrient recovery.*

  The intention of this category is to provide a quantitative measure of a product's design for recyclability and/or compostability. The larger the percentage of a product and/or its components that remain in a technical and/or biological metabolism, the better the score for this category".

- Material reutilization Score (MRS), the nutrient management strategy, the and the nutrient cycling are the indicators used to evaluate this category. The MRS is calculated as:

$$\frac{\begin{bmatrix}\%\ recycled\ or\ rapidly\ renewable \\ product\ content\end{bmatrix} + 2\begin{bmatrix}\%\ of\ product\ recyclable \\ or\ biodegradable/compostable\end{bmatrix}}{3} x100$$

- Houseful highlights

Main objective:	Use of existent agreed and harmonised indicators. Material Reutilization Score (MRS) has the aim to eliminate the concept of "Waste" and it is directly aligned with the Circular Economy.
Action:	a) Analyse the C2C methodology

[41] C2C - Public resources. Cradle to cradle certified™, Product Standard v.3.1., 2016. Cradle to Cradle Products Innovations Institute, prepared by MBDC in collaboration with the Environmental Protection Encouragement Agency, GmbH.

2.4.5 SDI - Sustainable Development Indicators framework

According to the European Commission Communication on a monitoring framework for the circular economy (Ref. 8): "The transition to a circular economy is a tremendous opportunity to transform our economy and make it more sustainable, contribute to climate goals and the preservation of the world's resources, create local jobs and generate competitive advantages for Europe in a world that is undergoing profound changes. The importance of the circular economy to European industry was recently highlighted in the renewed EU industrial policy strategy[42]. The transition to a circular economy will also help to meet the objectives of the 2030 Agenda for Sustainable Development[43]".

- (Ref. 15) **The 2030 Agenda for Sustainable Development[44]** includes 17 goals (see Figure 2.13), 169 targets and 230 separate indicators.
  "The Goals and targets will be followed up and reviewed using a set of global indicators. These will be complemented by indicators at the regional and national levels which will be developed by Member States, in addition to the outcomes of work undertaken for the development of the baselines for those targets where national and global baseline data does not yet exist. The global indicator framework, to be developed by the Inter Agency and Expert Group on Sustainable Development Goal Indicators, will be agreed by the Statistical Commission by March 2016 and adopted thereafter by the Economic and Social Council and the General Assembly, in line with existing mandates. This framework will be simple yet robust, address all Sustainable Development Goals and targets, including for means of implementation, and preserve the political balance, integration and ambition contained therein."

- (Ref. 18) Shows the Sustainable Development Goals (SDG) considered in the 2030 Agenda for Sustainable Development directly related to circular economy:
  "The circular economy (SDG 6, 8, 9, 11, 12, 13, 14, 15) offers a transformative agenda with significant new jobs and growth potential and stimulating sustainable consumption and production patterns. Focus on resource efficiency and minimising waste in a context of rapid global resource depletion gives the EU a competitive edge and stimulates innovation. It creates local jobs, at all skills levels and with opportunities for social integration. The transition to the circular economy offers a chance for Europe to modernise its economy, making it more future proof, green and competitive. The circular economy also contributes to lower carbon dioxide emission levels and energy savings as well as decreased air, soil and water pollution. Implementation of the 2015 circular economy action plan remains high on the agenda of the Commission as confirmed in the 2017 Work Programme." See Table 2.4

[42] COM (2017) 479

[43] https://ec.europa.eu/info/strategy/international-strategies/sustainable-development-goals/eu-approach-sustainable-development_en

[44] https://sustainabledevelopment.un.org/post2015/transformingourworld

Goal 1	End poverty in all its forms everywhere
Goal 2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 3	Ensure healthy lives and promote well-being for all at all ages
Goal 4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5	Achieve gender equality and empower all women and girls
Goal 6	**Ensure availability and sustainable management of water and sanitation for all**
Goal 7	Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 8	**Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all**
Goal 9	**Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation**
Goal 10	Reduce inequality within and among countries
Goal 11	**Make cities and human settlements inclusive, safe, resilient and sustainable**
Goal 12	**Ensure sustainable consumption and production patterns**
Goal 13	**Take urgent action to combat climate change and its impacts**
Goal 14	**Conserve and sustainably use the oceans, seas and marine resources for sustainable development**
Goal 15	**Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss**
Goal 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Goal 17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Table 2.4: Sustainable Development Goals (SDGs)[45]

Source: Adapted from COM (2016) 739 final (Ref. 18)

[45] Highlighting those directly linked to circular economy

Figure 2.13: Sustainable Development Goals: 17 goals, 169 targets, 230 separate indicators. The 2030 Agenda for Sustainable Development

Source: (Ref. 17) Nicola Massarelli, 2016

- Houseful highlights

Main objective:	Need to select an appropriate number of indicators having in mind the feasibility to its use (replicability, calculation tools, etc.). Focussing at the building scale but having in mind the global framework as a reference.
Action:	a) Follow up the evolution of the existing indicators available at Eurostat

3 The construction sector towards the Circular Economy

Construction circularity implies that everything: products, buildings, roads, etc. need to be designed as temporary structures, thereby preserving material at the highest level of quality, in order to ensure their usability in the future. Circularity in this context means to facilitate current needs in a way, which is not compromising future needs by using resources in a way that they remain available for future use. This aspect of avoiding lasting consequences is not limited to the preservation of materials; it also comprises energy resources, water and biodiversity.

The following sections compile the works focused on the current and legal and standardisation framework; the European Level(s) initiative and other references regarding circular economy (European founded projects and research studies).

3.1 Sustainability of construction works by CEN/TC 350

Source: Business plan at https://standards.cen.e

"The TC 350 is responsible for the development of horizontal standardised methods for the assessment of the sustainability aspects of new and existing construction works (buildings and civil engineering works), including standards for the environmental product declaration of construction products (EPD).

The standards are generally applicable (horizontal) and relevant for the sustainability assessment of construction works over their life cycle to support decision making in the life cycle of new and existing works.

The standards describe coherent methodologies for the assessment of sustainability aspects of construction products and construction works in terms of environmental, social and economic performance.

As the assessment methods incorporated in the standards of CEN/TC350 are utilizing performance based approach, i.e. the principal rule governing the legal framework of the construction products, CPR (EU Regulation No 305/2011 "Laying down harmonized conditions for the marketing of construction products"), the standards of CEN/TC350 give a possibility to ensure the same EU-harmonized level of playing field for the different aspects of sustainability underlying the Basic Requirements for Construction Works set in the Annex I of the CPR.

As a consequence, when the possible sustainability criteria are set in public procurement or building regulations, potential barriers to trade can be avoided by the use of these standards in the Internal Market and also in the global market."

The list of CEN/TC 350 published standards can be found at: https://standards.cen.eu filtering by Committee.

Relevant standards are briefly described in the next sections: Assessment of environmental performance of building products and buildings); Assessment of social performance of buildings and assessment of economic performance of buildings."

3.1.1 Assessment of environmental performance of building products

- EN 15804:2012+A2:2019 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products

"This European standard provides core product category rules (PCR) for Type III environmental declarations for any construction product and construction service. NOTE The assessment of social and economic performances at product level is not covered by this standard. The core PCR: - defines the parameters to be declared and the way in which they are collated and reported, - describes which stages of a product's life cycle are considered in the EPD and which processes are to be included in the life cycle stages, - defines rules for the development of scenarios, - includes the rules for calculating the Life Cycle Inventory and the Life Cycle Impact Assessment underlying the EPD, including the specification of the data quality to be applied, - includes the rules for reporting predetermined, environmental and health information, that is not covered by LCA for a product, construction process and construction service where necessary, - defines the conditions under which construction products can be compared based on the information provided by EPD. For the EPD of construction services the same rules and requirements apply as for the EPD of construction products."

3.1.2 Assessment of environmental performance of buildings

- prEN 15978 rev (it supersedes EN 15978:2011 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method)

Source: https://standards.cen.e

"This European Standard specifies the calculation method, based on Life Cycle Assessment (LCA) and other quantified environmental information, to assess the environmental performance of a building, and gives the means for the reporting and communication of the outcome of the assessment. The standard is applicable to new and existing buildings and refurbishment projects. The standard gives: - the description of the object of assessment; - the system boundary that applies at the building level; - the procedure to be used for the inventory analysis; - the list of indicators and procedures for the calculations of these indicators; - the requirements for presentation of the results in reporting and communication; - and the requirements for the data necessary for the calculation. The approach to the assessment covers all stages of the building life cycle and is based on data obtained from Environmental Product Declarations (EPD), their "information modules" (EN 15804) and other information necessary and relevant for carrying out the assessment. The assessment includes all building related construction products, processes and services, used over the life cycle of the building. The interpretation and value judgments of the results of the assessment are not within the scope of this European Standard."

3.1.3 Assessment of social performance of buildings

- EN 16309:2014+A1:2014 Sustainability of construction works - Assessment of social performance of buildings - Calculation methodology

Source: https://standards.cen.e

"This European Standard is one part of a suite of European Standards. The standard provides the specific methods and requirements for the assessment of social performance of a building while taking into account the building's functionality and technical characteristics. This European Standard applies to all types of buildings, both new and existing. In this first version of the standard, the social dimension of sustainability concentrates on the assessment of aspects and impacts for the use stage of a building expressed using the following social performance categories (from EN 15643 3): - accessibility; - adaptability; - health and comfort; - impacts on the neighbourhood; - maintenance; - safety and security. NOTE 1 Only impacts and aspects of the above social performance categories are deemed to have an agreed basis for European standardization at this time. Two of the social performance categories included in EN 15643–3 (sourcing of materials and services and stakeholder involvement) are not deemed to be ready for standardization at this time and will be considered for inclusion in future versions of this standard (see informative Annex C). This standard does not set the rules for how building assessment schemes may provide valuation methods. Nor does it prescribe levels, classes or benchmarks of performance. Valuation methods, levels, classes or benchmarks may be prescribed in the requirements for environmental, social and economic performance in the client's brief, building regulations, national standards, national codes of practice, building assessment and certification schemes, etc. NOTE 2 Where National building regulations give minimum requirements and reference to assessment methods on these aspects, the social performance determined by assessment according to this standard can be used to determine the degree to which the building goes beyond the regulatory/legal requirements. The corporate social responsibility (CSR) of organizations is not covered by this standard. The standard gives requirements for: - the description of the object of assessment; - the system boundary that applies at the building level; - the list of indicators and procedures for the application of these indicators; - the presentation of the results in reporting and communication; - the data necessary for the application of the standard, and - verification."

3.1.4 Assessment of economic performance of buildings

- EN 15643-4. Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance

Source: https://standards.cen.e

"This European Standard form one part of a series of European Standards for the assessment of buildings and provides specific principles and requirements for the assessment of economic performance of buildings taking into account technical

characteristics and functionality of a building. Assessment of economical performance is one aspect of sustainability assessment of buildings under the general framework of EN 15643-1. The framework applies to all types of buildings and it is relevant for the assessment of the economic performance of new buildings over their life cycle, and of existing buildings over their remaining service life and end of life stage. The economic performance assessment of a building addresses the life cycle costs and other economic aspects, all expressed through quantitative indicators. It excludes the economic risk assessment of a building and return on investment calculations It includes economic aspects of a building relating to the built environment within the area of the building site, it does not include economic aspects beyond the area of the building site, e.g. such as economic impacts of construction of local infrastructure or economic impacts resulting from transportation of the users of the building or economic impacts of a construction project on local community. The standards developed under this framework do not set the rules for how the different assessment methodologies may provide valuation methods nor do they prescribe levels, classes or benchmarks for measuring performance. NOTE Valuation methods, levels, classes or benchmarks may be prescribed in the requirements for economic performance in the client's brief, building regulations, national standards, national codes of practice, building assessment and certification schemes, etc. The rules for assessment of economic aspects of organizations, such as management systems, are not included within this framework. However, the consequences of decisions or actions that influence the economic performance of the object of assessment are taken into account."

- EN 16627:2015 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods

Source: https://standards.cen.e

"This European Standard specifies the calculation methods, based on Life Cycle Costing (LCC) and other quantified economic information, to assess the economic performance of a building, and gives the means for the reporting and communication of the outcome of the assessment. This European Standard is applicable to new and existing buildings and refurbishment projects. This European Standard gives: - the description of the object of assessment; - the system boundary that applies at the building level; - the scope and procedure to be used for the analysis; - the list of indicators and procedures for the calculations of these indicators; - the requirements for presentation of the results in reporting and communication; - and the requirements for the data necessary for the calculation. The approach to the assessment covers all stages of the building life cycle and includes all building related construction products, processes and services, used over the life cycle of the building. The interpretation and value judgments of the results of the assessment are not within the scope of this European Standard."

- ISO 15686-5:2017 Buildings and constructed assets - Service life planning - Part 5: Life-cycle costing

Source: https://www.iso.org

This international standard provides requirements and guidelines for performing life-cycle cost (LCC) analyses of buildings and constructed assets and their parts, whether new or existing.

NOTE 1 Life-cycle costing takes into account cost or cash flows, i.e. relevant costs (and income and externalities if included in the agreed scope) arising from acquisition through operation to disposal.

NOTE 2 Life-cycle costing typically includes a comparison between alternatives or an estimate of future costs at portfolio, project or component level. Life-cycle costing is performed over an agreed period of analysis, clearly identifying whether the analysis is for only part of or for the entire life cycle of the constructed asset.

3.1.5 Houseful highlights

15804 (environmental performance of building products)

- Based on the "modularity principle": Where processes influence the product's environmental performance during its life cycle, they shall be assigned to the module of the life cycle where they occur; all environmental aspects and impacts are declared in the life cycle stage where they appear. The modules divide the whole life cycle in different stages (See Figure 3.1):
    - Product stage (raw materials supply, transport, manufacturing)
    - Construction process stage (transport, construction/installation process)
    - Use stage (use, maintenance, repair, replacement, refurbishment)
    - Benefits and loads beyond the system (reuse, recovery, recycling potential)
- Core environmental impact indicators
- Additional environmental impact indicators
- Indicators describing resource use and environmental information based on Life Cycle Inventory (LCI)

15978 (environmental performance of building)

- Based on the "modularity principle", as mentioned above.
- Indicators according to the standard EN 15804

16627 (economic performance of buildings)

- Based on the "modularity principle", as mentioned above.
- Indicators related to:
    - Calculation of the Discount Factor
    - Net Present Value (NPV), Net Present Cost (NPC)
    - Annual Cost and Annual Equivalent Value (AC or AEV)
    - Other economic indicators
    - Costs and related indicators (costs and incomes associated with the object of assessment during its whole life cycle).

16309 (social performance of buildings)

- It covers only the use stage. However, module B1 is the major information module in the life cycle stage of the building.
    - Module B1. Use
    - Module B2. Maintenance
    - Module B3. Repair
    - Module B4. Replacement
    - Module B5. Refurbishment
    - Module B6. Operational energy use
    - Module B7. Operational water use.
- The social performance measures will be represented through indicators for the following social performance categories:
    - Accessibility
    - Adaptability
    - Health and comfort
    - Loadings on the neighbourhood
    - Maintenance
    - safety / security

  Two other categories as sourcing of materials and services and stakeholder involvement are expected to be included in future versions

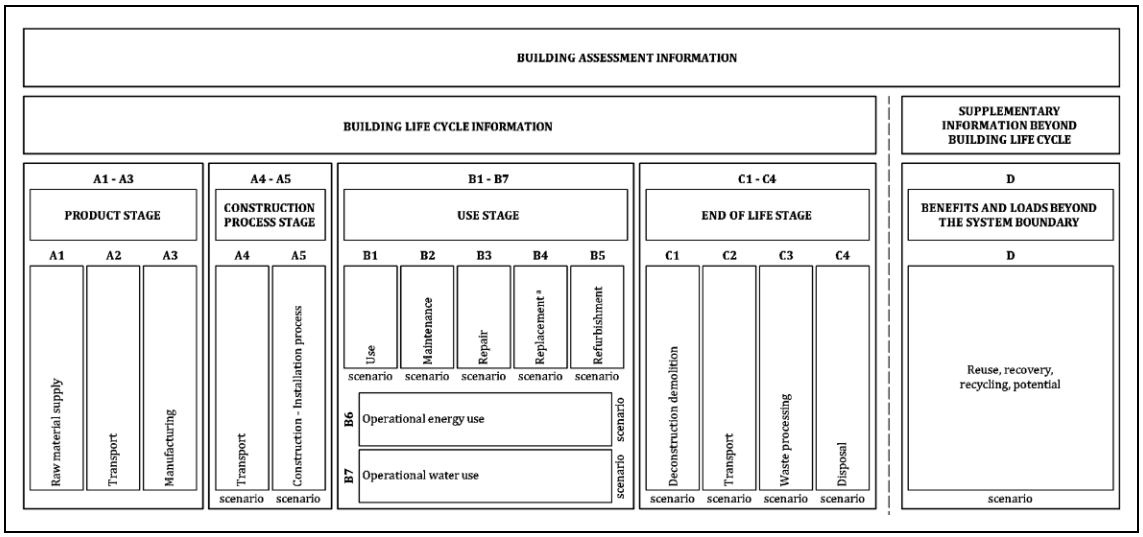


Figure 3.1: Life cycle stages and modules for the building assessment

Source: Adapted from EN 15804:2012+A2:2019

3.2 Resource Efficiency Opportunities in the Building Sector

Source: Ref. 33 European Commission, COM (2014) 445 final, Communication on resource efficiency opportunities in the building sector.

"Steps forward – need for objective and reliable data

To enable professionals, decision makers and investors throughout the EU to use life-cycle aspects, they need empirical based, reliable, transparent and

comparable data[46], which in turn will have to be based on clear indicators for building performance which combine the objectives of different public and private requirements. While different national and commercial schemes may have reasons to diverge slightly in their approaches (e.g. specific materials or climatic considerations), a common framework of core indicators, focusing on the most essential aspects of environmental impacts should nonetheless be established. This will allow comparability and provide consumers and policy makers with easier access to reliable and consistent information.

A single framework with core indicators will:

- *Allow easier communication of information to professional and non-experts;*
- *Provide reliable and comparable data to be used in decision-making covering the entire life cycle of buildings;*
- *Enable the setting of clear objectives and targets, including system boundaries, for building performance, complementing already existing European legislation on buildings[47];*
- *Increase awareness of the benefits of sustainable buildings among actors engaged in providing buildings, as well as private and public clients, including users of buildings;*
- *Facilitate the effective transfer of good practices from one country to another;*
- *Reduce the cost to assess effectively and communicate the environmental performance of buildings;*
- *Provide public authorities with access to core indicators and to a critical mass of relevant data on which to base their policy initiatives, including Green Public Procurement;*
- *Widen the market for sustainable buildings to more countries than current trends indicate and to other buildings sectors such as non-residential buildings and, eventually, to the residential market."*

"Steps forward – selecting reliable indicators

In collaboration with stakeholders, the Commission will develop a framework consisting of core indicators, including their underlying methods, to be used to assess the environmental performance of buildings throughout their life cycle. Based on existing policies, regulations and data[48] at EU and national level, and without pre-empting the results of future work, this process should as a minimum investigate the following areas[49]:

[46] Commission Recommendation 2013/179/EU on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations.

[47] In addition, also to support the future development of Sustainable cities criteria as described in the 7th Environment Action Programme, http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:354:0171:0200:EN:PDF

[48] Waste Data Centre; Natural Resources Data Centre; Resource Efficiency Scoreboard European Platform on Life Cycle Assessment

[49] The Public Consultation organised in relation to this initiative concluded on the listed areas. Indoor comfort was not included in the consultation but has been emphasised by stakeholders.

- *Total energy use, including operational energy[50] (based on existing legislation) and embodied energy of products and construction processes*
- *Material use and the embodied environmental impacts[51]*
- *Durability of construction products*
- *Design for deconstruction*
- *Management of construction as well as demolition waste (CDW)*
- *Recycled content in construction materials*
- *Recyclability and reusability of construction materials and products*
- *Water used by buildings[52]*
- *The use intensity of (mostly public) buildings (e.g. flexible functionality for different users during different times of the day)[53]*
- *Indoor comfort"*

3.3 Level(s)

Source: https://ec.europa.eu/environment/eussd/buildings.htm

In 2014, the European Commission adopted the Communication "Resource efficiency opportunities in the building sector" (Ref. 33). The general objective of this initiative is to reduce the environmental impact of buildings by improving the overall resource efficiency and, as a consequence, to improve the related competitiveness of construction businesses.

This identified the need for a common EU approach to the assessment of the environmental performance of buildings: a 'common framework of core indicators', rigorous enough to drive improvement in performance and allow for comparison between buildings.

In 2015, Circular Economy Action Plan (Ref. 19) furthermore reiterates this objective and adds that, given the long lifetime of buildings, it is essential to encourage design improvements that will reduce their environmental impacts and increase the durability and recyclability of their components.

Since then, the work started the Level(s) framework - a flexible system of indicators, that can be incorporated into new and existing assessment schemes, or be used on their own by a diverse range of stakeholders, including public authorities, design teams and property investors.

Level(s) is one of the tools and instruments that have been developed by the Commission to facilitate the transition towards a more Circular Economy.

[50] While the use phase depends on design and construction as well as on the behaviour of the occupants, the latter is not the focus of this initiative.

[51] When appropriate, also taking into account the use of green infrastructure elements such as green roofs and green walls, COM (2013)249, http://ec.europa.eu/environment/nature/ecosystems/index_en.htm

[52] See footnote on energy use above.

[53] In order to adapt the need for further built environment (e.g., use empty instead of new buildings, use buildings for more than one purpose, build buildings to be adapted to new functions or changing needs).

According to the dedicated web page to explain each of these tools[54]:

"Level(s) is a voluntary reporting framework to improve the sustainability of buildings. Using existing standards, Level(s) provides an EU-wide approach to assessing environmental performance in the built environment. It encourages life cycle thinking for the whole building by offering a step by step approach to life cycle assessment"[55].

The building sector is a big consumer of resources in Europe. It uses about half of all materials extracted, half of all energy consumed and one third of all water consumed, and it generates one third of all waste. Environmental pressures arise at different stages of a building's life-cycle.

However, this also means that the building sector offers an enormous potential for setting the circular economy business case, including opportunities for sustainable building design, construction, repair, maintenance, as well as recycling and reuse of materials in the end of a building's lifespan. These opportunities have been increasingly recognised by the European Commission, which in 2014 adopted the Communication on Resource Efficiency Opportunities in the Building Sector and later on placed a special focus on sustainable buildings in the Circular Economy Action Plan. The Action Plan includes an action on the assessment of the environmental performance of buildings. To support such assessment, the Commission has developed a framework with indicators, called Level(s). It is a simple entry point to what can be a very complex area and covers energy, materials, water, health and comfort, climate change and life cycle cost and value".

3.3.1 Houseful highlights

- The selection of the KPIs have to take into account the current standards development and the dedicated instruments developed by the European Union to facilitate the transition towards a more Circular Economy. See Table 3.1

[54] https://ec.europa.eu/environment/green-growth/tools-instruments/index_en.htm#levels

Macro-objective	Description	Indicator/tool
Greenhouse gas emissions along a buildings life cycle	Minimise the total GHG emissions along the building lifecycle	Use stage energy performance
		Life cycle global warming potential
Resource efficient and circular material life cycles	Optimise building design to support lean and circular flows, extend long-term material utility and reduce significant environmental impacts	Life cycle tools: bill of materials
		Life cycle tools: scenarios for life span, adaptability and deconst.
		Construction and demolition waste and materials
		Cradle-to-grave LCA
Efficient use of water resources	Make efficient use of water resources	Total water consumption
Healthy and comfortable spaces	Create buildings that are comfortable, attractive and productive to live and work in and which protect human health.	Indoor air quality
		Time outside of thermal comfort range
Adaptation and resilience to climate change	Futureproof building performance to projected changes in the climate	Life cycle tools: scenarios for projected future climatic conditions
Optimise life cycle cost and value	Optimise the life cycle cost and value of buildings	Life cycle costs
		Value creation and risk factors

The calculation methods recommended for the LCA indicators are provided by CEN standards EN 15804 and EN 15978.

Table 3.1: Indicators proposed in Level(s)

Source: Ref. 34 Model for Life Cycle Assessment (LCA) of buildings. Joint Research Centre (JRC), the European Commission's science and knowledge service. Gervasio, H. & Dimova, S., 2018

3.4 Selection of funded projects related to CE

This section compiles some of the European projects that address the circular economy in buildings or that are related to the construction sector. Additional information can be founded at:

- Ref. 20 Research & Innovation Projects relevant to the Circular Economy Strategy. CALLS 2016 – 2018. Directorate-General for Research and Innovation, 2019.
- H2020 projects: https://cordis.europa.eu/search/en
- List of databases of EU-funded research and innovation projects[56]

3.4.1 H2020 project: BAMB - buildings as material banks:

Source: https://www.bamb2020.eu/

BAMB is creating ways to increase the value of building materials. Dynamically and flexibly designed buildings can be incorporated into a circular economy – where materials in buildings sustain their value. That will lead to waste reduction and the use of fewer virgin resources.

The EU funded BAMB project brings 15 parties throughout Europe together for one mission – enabling a systemic shift in the building sector by creating circular solutions.

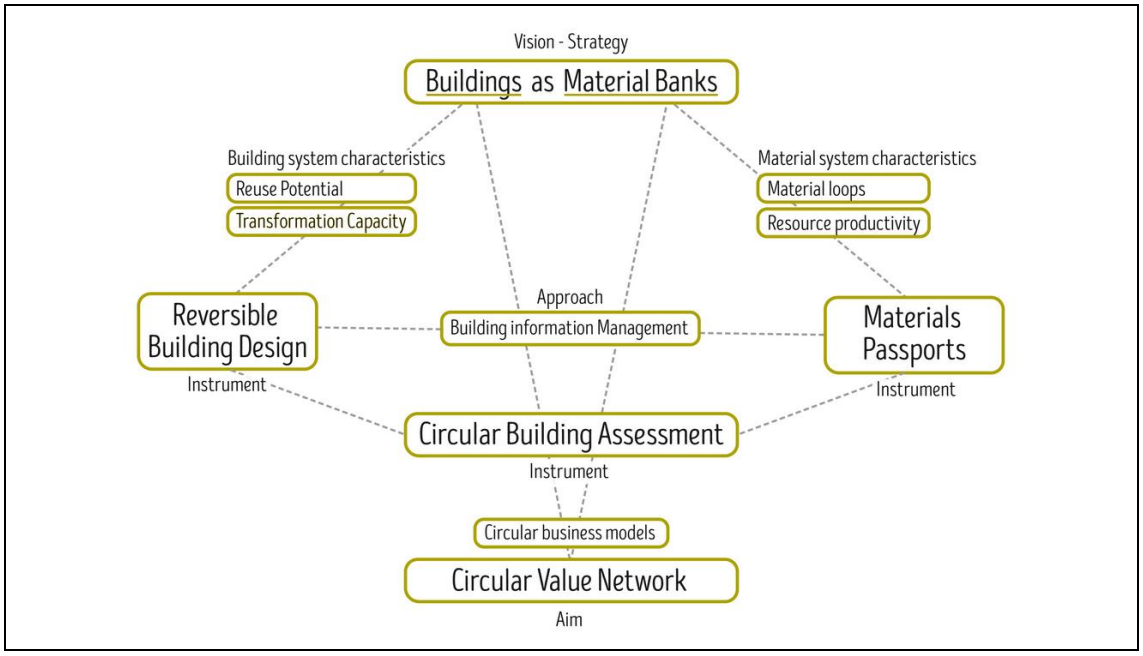


Figure 3.2: BAMB project, Common language

Source: retrieved from BAMB web site

[56] https://ec.europa.eu/info/research-and-innovation/projects/project-databases_en

Circular Building Assessment - A new tool made possible by BAMB. Hobbs, G. (BAMB, Ref. 24)[57]. It considers the following indicators: - Reclaimed content - Virgin/primary resource indicator - Recycled content - Reuse potential / RBD[58] score - Life-cycle co-ordination[59] - Transformation capacity[60] - Recyclability
Reversible Building design guidelines and protocol. Durmisevic. E, 2018. (BAMB, Ref. 25)[61] It considers the following indicators: - Future reuse potential of materials/product/components - Reclaimed materials/product/components - Extending building life cycle - Reusable partitioning - Reversible bonding Additional indicators of reversible building: - Reversibility of space (adapt space) - Reversibility of structure (reconfigure / upgrade structure) - Reversibility of material (separate elements/material)

3.4.2 H2020 project: FISSAC

Source: http://fissacproject.eu/en

The FISSAC project involves stakeholders at all levels of the construction and demolition value chain to develop a methodology, and software platform to facilitate information exchange, that can support industrial symbiosis networks and replicate pilot schemes at local and regional levels.

The model will be based on three sustainability pillars:

- Environmental (with a life-cycle approach)
- Economic
- Social (taking into consideration stakeholder engagement and impact on society).

Our ambition is that the model we create can be replicated in other regions and other value chain scenarios.

[57] https://www.bamb2020.eu/wp-content/uploads/2018/09/Hobbs.pdf

[58] RDB: Reversible Building Design

[59] Life-cycle co-ordination: assembly of materials, which have different life cycles; and assembly of materials, whose functions have different life cycles.

[60] Masseurs the effort needed to transform the buildings as well as the type and number of options.

[61] https://www.bamb2020.eu/wp-content/uploads/2018/12/Reversible-Building-Design-guidelines-and-protocol.pdf

FISSAC aims to demonstrate the effectiveness of the processes, services, and products at different levels.

	Indicators
ENVIRONMENTAL	Material consumption (primary and secondary raw material consumption)
	Energy consumption (fuel, thermal energy, electricity, renewable energy consumption)
	Exergy
	Air emissions (GHG and other emissions)
	Solid waste generation (hazardous and non-hazardous wastes)
	By-products
	Life cycle indicators (resource depletion, carbon/water/ecological footprints, cumulative energy and exergy demand, life cycle cost)
ECONOMIC	Product quantity
	Turnover
	Net value added
	OPEX (material, energy etc. costs, environmental cost savings, revenues from IS activities)
	CAPEX
SOCIAL	Job creation and retention
	Creation of IS
	Social responsibility
	Lifelong learning
	Health and safety at work
	Rate of community participation
	Level of social acceptance
	Community development
	Innovation and investment in R&D
CIRCULARITY	Environmental impact momentum
	Utility (lifetime and function served)
	Environmental cost effectiveness
NSA	Betweenness and closeness
	Reciprocity
	Intensity

Table 3.2: Indicators groups for monitoring Industrial Symbiosis

Source: Ref. 26 Fissac Project, Deliverable 1.6, Industrial Symbiosis Indicators, 2016 (Ozge Y. et al).

3.4.3 H2020 project: PLUG-N-HARVEST

PLUG-N-HARVEST[62] stands for Plug-n-play passive and active multi-modal energy Harvesting systems, circular economy by design, with high replicability for Self-sufficient Districts and Near-Zero Buildings.

PLUG-N-HARVEST is a four-year project funded by the EU's H2020 programme, which strategic goal is to design, develop demonstrate and exploit a new modular, plug-n-play concept/product for Advanced Dynamic Building Envelopes (ADBE), deployable to both residential and non-residential buildings. The proposed system should be able to provide high energy use reduction and high energy harvesting from renewable energy sources (RES) both at the single-building and the district scale while requiring medium-to-low installation costs and almost-zero operational costs.

[62] https://www.plug-n-harvest.eu

PLUG-N-HARVEST has carried out a selection of relevant Key Performance Indicators (KPIs) to evaluate: a) the project's main goals; and b) the degree of compliance of circular economy (CE) principles of a building retrofitting action.

The KPIs to assess project's performance are listed in Table 3.3:

Number and Acronym		Name	Units	PLUG-N-HARVEST KO	LEV. MO[63]	LEVEL Code[64]		Responsible Partner
KPI 1	PECRP	Primary Energy consumption reduction percentage after retrofitting (country specific)	%	KO1, KO2, KO3, KO5, KO6	MO1	1.1	1.1.1	CU
KPI 2	EBRP	End Energy Bill Reduction Percentage	%	KO1, KO2, KO3, KO5, KO6	MO1	1.1	1.1.3	CU
KPI 3	RER	Renewable Energy Ratio	%	KO1, KO2, KO3, KO5, KO6	-	-	-	CU
KPI 4	Waste	Waste disposed	%	KO1, KO2, KO3, KO5, KO6	MO2	2.3	2.3.1	EIG
KPI 5	Cyclability	Products' (level 1) Degree of Cyclability	%	KO1, KO2, KO3, KO5, KO6	-	-	-	EIG
KPI 6	Modularity	Circular Inventory of Active Cycling	%	KO1, KO2, KO3, KO5, KO6	-	-	-	AIGUASOL
KP1 7	Disassembly	Design for Disassembly	%	KO1, KO5, KO6	-	-	-	AIGUASOL
KP1 8	GHG Payback	GHG emissions payback time	%	KO1, KO2, KO3, KO5, KO6	MO2	2.4	2.4.2	EIG
KP1 9	Toxic Mat	Use of toxic materials	%	KO1, KO2, KO3, KO5, KO6	MO4	-	-	EIG
KP1 10	INDOOR disc	Indoor discomfort	%	KO2, KO6	MO4	4.2	4.2.1	CERTH ConvCAO

[63] Level(s) Macro-Objective
[64] Code for Level indicator. There are several indicators for every macro objective.

Number and Acronym		Name	Units	PLUG-N-HARVEST KO	LEV. MO[63]	LEVEL Code[64]		Responsible Partner
KP1 11	PP	Payback Period	*Years*	KO1, KO2, KO3, KO5, KO6	MO6	6.1	6.1.1	AIGUASOL
KP1 12	OPEX	Operation Expenditures	*€/year*	KO5, KO6	MO6	6.1	6.1.3	AIGUASOL
KP1 13	LCC	Life cycle cost	*€/m2/ year*	KO1, KO2, KO3, KO5, KO6	MO6	6.1	6.1.4	CERTH CPERI
KP1 14	EROI	Energy Return on Investment or Energy Payback Time	*years*	KO1, KO2, KO3, KO5, KO6	MO6	6.1	6.1.5	ETRA
KP1 15	ADBEcost	Costs for PLUG-N-HARVEST ADBE per m²-façade	*€/m² façade*	KO1, KO5, KO6	-	-	-	ALUMIL
KP1 16	CostDiff	Cost difference to conventional retrofitting, building automation, conventional ADBE	*%*	KO1, KO5, KO6	-	-	-	ALUMIL
KP1 17	S&P Experience	User Satisfaction with Privacy and Security	*0-5*	KO4, KO6	-	-	-	ODINS

Table 3.3: PLUG-N-HARVEST KPIs to evaluate project's success

Source: Aiguasol

These indicators have been validated by means of a survey completed by external experts and stakeholders.

As shown, several of the listed KPIs are not directly related with Building Circularity. However, in the context of this project, a methodology to evaluate the degree of compliance of CE principles is also being prepared, which is fully aligned with HOUSEFUL's objectives and approach. Although it has not already been completed, this methodology proposes the assessment of four vectors related with CE principles:

- Energy use: Energy Circularity Indicator, in percentage.
- Materials use: Materials Circularity Indicator, in percentage.
- Social impact: Social Added Value Circularity Indicator, in percentage.
- Economic value: Economic and Business Circularity Assessment. This is presented as clearly separated from the previous three and has monetary units.

The assessment contemplates all building life cycle stages, from product (cradle) to end-of-life treatment processes (grave). It is also worth highlighting that the degree

of circularity for energy and materials is measured as the amount of "circular flows" (i.e. renewable energy and cycled materials, respectively), whereas for social impact it is measured as how many positive impacts are addressed out of the total number of positive impacts theoretically possible to be addressed. For the economic value, they propose a sort of Life-Cycle Costing (LCC) analysis, incorporating positive and negative externalities.

3.4.4 Houseful highlights

BAMB - buildings as material banks

- Indicators focussing on material resources and paying attention on innovative concepts as transformation capacity, reversible design and life cycle coordination (assembly of materials which have different life cycles, and assembly of materials whose functions have different life cycles), etc.
- BAMB web site, section common language, as a reference for good explanation of the circularity concepts.

FISSAC

- Indicators focused on industrial symbiosis.

PLUG-N-HARVEST

The project has come up with a methodology to evaluate the degree of compliance of CE principles focusing on four aspects: energy and materials use, social impact and economic value. The methodology is aligned with current normative for building life-cycle assessment, therefore contemplating all stages of a building's life cycle. However, it is still pending from a refining process to fully align with project's goals.

The CE compliance contemplates the assessment of four aspects:

- Energy consumption
- Materials use
- Social impact
- Life-cycle economic value

The degree of circularity is proposed to be presented for all building life-cycle and also broken down by stages.

3.5 Other specific reference documents about circular economy methodology and KPI applied to buildings

Although some of the documents listed below has been already quoted along the report and there is an specific section for the bibliography, this selection aims to remark some of the references because of their connexion to the circularity in the building and construction sector.

- Ref. 27 Building Circularity Indicators. An approach for measuring circularity of a building. Jeroen Verberne, 2016

- Ref. 36 Madaster Circularity Indicator explained v1.1. Madaster
- Ref. 35 The circular economy in the built environment. ARUP. 2016
- Ref. 31 Blockchain for a circular economy. Explorative research towards the possibilities for blockchain technology to enhance the implementation of material passports. J.T. (Jesse) Rudolphi, 2018
- Overview reports and publications of the BAMB project[65]
- Ref. 37 Circular Economy Closing loops means being fit for the future. DGNB, January 2019
- Ref. 38 Resource efficiency in the building sector Final report Client: DG Environment Rotterdam. Ecorys, Márton H. et al, 2014.
- Ref. 39 Level(s) – A common EU framework of core sustainability indicators for office and residential buildings, Parts 1 and 2: Introduction to Level(s) and how it works (Beta v1.0), JRC Technical Report, EC. Dodd, N. et al, 2017.
- Ref. 40 Level(s) – A common EU framework of core sustainability indicators for office and residential buildings, Part 3: How to make performance assessments using Level(s) (Beta v1.0), JRC Technical Report, EC. Dodd, N. et al, 2017.

[65] https://www.bamb2020.eu/library/overview-reports-and-publications/

4 KPIs selection

The purpose of HOUSEFUL Key Performance Indicators (KPIs) is to set up a clear and unambiguous circularity measurement framework encompassing the various aspects of the Circular Economy addressed by HOUSEFUL proposed solutions:

- Energy use
- Water use
- Materials consumption
- Social impact
- Environmental impact
- Economic life cycle cost and value

These indicators will be later used to define a holistic evaluation methodology to characterize the depth of the accomplishment of the Circular Economy principles of a new building construction and / or major renovation process. This process will be carried out within HOUSEFUL's T2.4 and described in the related Deliverable D2.4.

HOUSEFUL approach focuses on the reuse of existing indicators that suit current EU legislation -or planned legislation. According to the previous project references presented, BAMB (BAMB 2020, 2016) and PLUG-N-HARVEST (Plug-n-Harvest 2021, 2017) H2020 projects, Level(s) methodology for Sustainability assessment of the built environment (Dodd, Cordella, Traverso, & Donatello, 2017a, 2017b), Cradle to Cradle certification (Cradle to Cradle Products Innovation Institute, 2018) and Ellen MacArthur Materials Circularity Indicator (Ellen Macarthur Foundation & Granta Design, 2015) are the most relevant references for the scope of HOUSEFUL project.

As it has been previously described, each of those initiatives addresses the circularity from different approaches, each of them emphasizing on some of -but not all of- the HOSUEFUL pillars. In particular,

- Level(s) defines a common EU framework of core sustainability indicators for office and residential buildings. However, its focus on sustainability rather than Circular economy bias the approach to measuring the impacts rather than the degree of circular flows.
- BAMB is mainly focused on the development of a Materials Passport approach together with reversible building design and business models and policies recommendations. The BAMB's proposed Circularity assessment methodology is focused on the use of BIM modelling data to evaluate the circularity of the building from the bill of materials used.
- PLUG-N-HARVEST is mainly focused on the development of building façade retrofitting alternatives under the Circular Economy principles. Within the scope of the project a preliminary Building Circularity evaluation methodology has been developed, based on a set of main performance indicators. The PLUG-N-HARVEST's proposed Circularity assessment methodology approaches the building impacts from a holistic perspective, incorporating

energy consumption, social impact, materials use and economic perspectives into the evaluation methodology.

- Cradle-to-Cradle certification is a comprehensive approach for the evaluation of several aspects of Circular Economy including materials, energy and water use or social fairness and environmental impact. However, it is focused only on product stage rather than the entire life cycle of the evaluated product.
- Ellen MacArthur and Granta Design Circularity Indicator is based on the Materials Flow Analysis approach and focuses on the entire life cycle of the assessed product. However, this approach is fenced in the materials evaluation and, hence, it lacks the consideration of other pillars in order to be a complete evaluation of all vectors encompassed in CE.

All those initiatives have been analysed, in order to identify which are the most reliable indicators that should be taken into consideration. Those core common indicators have been adapted to the holistic approach of HOUSEFUL project, as far as they should ensure the replicability of the methodology across different regional contexts.

Next table indicates which are the HOUSEFUL KPIs

Indicator	short	Units	Description	Formula (if available)	Reference
Energy Circularity Indicator	**ECI**	*%*	Rate of circular energy to total lifecycle energy consumption of the building or retrofitting. By "circular energy", it is understood the renewable energy produced on-site or near places and the energy savings derived from the application of passive measures. Therefore, it explicitely excludes the RE coming from the grid. Expressed in %, but calculated in Primary Energy Terms	$ECI[\%] = \frac{RE_{A1-3} + RE_{A4-5} + RE_B + RE_C\,[kWh_{PE}]}{E_{th} + E_e\,[kWh_{PE}]}$	Adaptated from Ellen MacArthur Foundation "Materials Circularity Indicator"
Life Cycle Energy Consumption	**LCEC**	*kWh PE*	Complementary to the ECI, the Life Cycle Energy Consumption is the denominator of the calculation formula for the ECI and expresses the total energy consumption of the building along its life cycle. Expressed in Primary Energy.	$Lifecycle\ Energy\ Consumption[kWh_{PE}] = E_{th} + E_e$	Adaptated from LEVEL 1.1.1. Primary energy demand from LEVEL, expanding the scope from Use Stage (B) to Life Cycle Approach, according with EN 15978.
Energy Dependency Rate	**EDR**	*%*	The indicator shows the extent to which an economy relies upon imports in order to meet its energy needs. It is calculated as net imports divided by the sum of gross inland energy consumption plus maritime bunkers.	**Energy dependence = Net imports / ∑ Gross inland energy consumption + International maritime bunkers.** Net imports are calculated as total imports minus total exports. Gross inland consumption is a calculated value, defined as: Indigenous production + From other sources + Imports – Exports – International marine bunkers + Stock changes International Marine Bunkers are quantities of fuels delivered to ships of all flags that are engaged in international navigation. Calculated by EUROSTAT and publicly available	Eurostat: http://data.europa.eu/euodp/data/dataset/rn3OngWhEmmS9UM8DCFKw
Share of RE in Gross Energy Consumption of country	**SRE**	*%*	Based on the definitions included in the Directive 2009/28/EC(Renewable Energy Directive) on the promotion of the use of energy from renewable sources. This indicator measures how extensive is the use of renewable energy and, by implication, the degree to which renewable fuels have substituted fossil and/or nuclear fuels and therefore contributed to the decarbonisation of the EU economy.	Calculated by EUROSTAT and publicly available online	Eurostat: https://data.europa.eu/euodp/en/data/dataset/Ug0WD36X7WkvGhWm8dRLQw
Materials Circularity Indicator	**MCI**	*%*	Rate of circular material to total lifecycle material use of the building or retrofitting. By "circular material", it is understood: • Material from circular sources [Construction phase]: recycled content or renewable content according sources listed on Table 11 and aligned with Cradle to Cradle Certified Products Standard, i.e. recycled post-industrial, recycled post-consumer, reused materials, remanufactured materials, rapidly renewable materials, etc. • Cyclable material at the end of the its use [end of life phase] through Technical or Biological Cycle. The paths and strategies considered cyclable are listed and described in Table 12, and are aligned with Cradle to Cradle CertifiedTM Products Standard. • [Use phase]: What is the expected lifespan of the products used, as opposed to the average lifespan of similar products.	$MCI[\%] = \frac{\sum TMI\ from\ Cycled\ Sources + \sum MO\ to\ Cycled\ Paths\ Sources\ [kg]}{\sum TMI + \sum TMO\ [kg]}$ Where the involved terms are: TMI [kg], Total Material Input to the building TMO [kg], Total Material Output from the building	Adapted from LEVELs & Ellen MacArthur Foundation & MADASTER Includes LEVEL(s) 2.1 BOM and 2.3 (C&DW), although that instead of listing them as LEVEL does, it calculates a ratio of cycled materials over the total materials use • Reference to section 5.2 of Madaster CI (https://www.madaster.com/application/files/3315/3483/8512/Madaster_Circularity_Indicator_explained_v1.1.pdf)
Total Material Input	**TMI**	*kg/m2*	Complementary to the MCI, Total Material Input to de building, from the Bill of Materials	Sum of Materials as in the Bill of Materials	From LEVEL(s) 2.1 Constructing the BOM
Critical Raw Materials	**CRM**	*Yes/No*	In 2011, European Commission (EC) published the first list of Critical Raw Materials (CRMs). CRM have been identified by EU to anticipate/prevent supply shortages, and to define policy actions on materials whose supply interruption would have critical consequences. From product and building perspective is critical to identify where these CRM are located and in which quantities to define programs of custody to assure proper take back of them	Binary (yes/no), detailing if a product or Subcomponent contains any ingredient listed in CRMs	Cradle to Cradle and European Commission
Quality of Reutilization Potential	**QRP**	*% of R-strategy*	• Further refinement of Cyclable material at the end of the its use [end of life phase] through Technical or Biological Cycle indicated by the 10-R model (starting from Reuse, Rapair, Refurbisch, Remanufacture, Repurpose, Recycle & Recover).	Indicate per element (product) in the building at the end of its lifecycle what potential R-strategy is applicable.	
Material Toxicity	**MT**	*1 to 5*	Toxic and unhealthy materials that suppose risks for people and environment need to be phased out in the circular model rather recirculated	Toxicity Indicator will be a rating (from 1 to 5), detailing if a product or Subcomponent contains problematic ingredients in terms of toxicity. Being 1 the maximum level of toxicity and 5 products completely safe for the uses considered.	Cradle to Cradle

Indicator	short	Units	Description	Formula (if available)	Reference
Water Circularity Indicator	**WCI**	%	Rate of circular water to total lifecycle water consumption of the building or retrofitting. By "circular water", it is understood the water content of the recycled / reused products and the recycled or rainwater harvested used during operations and/or end of life phases. "Circular Water" will explicitely include greywater, blackwater and rainwater use	$WCI[\%] = \frac{RW_{A1-3} + RW_{A4-5} + RW_B + RW_C\,[m^3]}{W\,[m^3]}$	Adaptation from Ellen MacArthur Foundation "Materials Circularity Indicator"
Life Cycle Water Consumption	**LCWC**	m^3	Complementary to the WCI, the Life Cycle Water Consumption is the denominator of the calculation formula for the WCI and expresses the total water consumption of the building along its life cycle. Expressed in m^3.	$Lifecycle\ Water\ Consumption[m^3] = W_{A1-3} + W_{A4-5} + W_B + W_C$	Similar to LEVEL(s) 3.1 Total Water Consumption, expanding the scope from Use Stage (B) to Life Cycle Approach, according with EN 15978. Includes Use Stage Water and Water Footprint
Water Exploitation Index	**WEI**	%	Measure of the total water use as a percentage of the renewable freshwater resources for a given territory and time scale. It is an indicator of water scarcity, providing information about the level of pressure on the natural water resources of a territory due to human developed activity	Calculated by EEA and available at https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-3	European Environment Agency: https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-3
Social Added Value	**SCI**	%	To be able to unify all the quantitative and qualitative values, the Social Added Value indicator will be expressed as the ratio between the total number of social impacts addressed within the project to the total number of social impacts potentially addressable according to the referred standards and building Life Cycle Stage based on a point calculation. The social impacts addressed will explicitely include different categories: Accessibility - Adaptability - Health & Comfort - Impacts on neighbourhood - Maintenance - Safety & Security	A1- A3 stages: C2C Achieved Level of Certification in Social Fairness Category (0 - 5 points from Basic to Platinum) A4 – A5 stages: Social performance of buildings under construction (0-3 points) B1 stage: Assessment of social performance of buildings (0 to 7 points, 1 for each category) B2 – B5 stages: Assessment of social performance of buildings (0 to 7 points, 1 for each category) C1 – C4 stages: Construction Activity Pollution Prevention (0-1 point)	Adapted mainly from LEVEL, EN 16309, EN15978, C2C and BREEAM. Expanding the scope of EN16309 from Use Stage (B) to Life Cycle Approach, according with EN 15978. Product stage: C2C Construction stage: BREEAM and C2Cfor Construction Stage Use stage: EN 16309 and LEVEL EoL: BREEAM
Energy Poverty	**EP**	%	Percentage of household income (average income of country) spent on energy bills. A household is said to be fuel poor if it needs to spend more than 10% of its income on fuel to maintain an adequate level of warmth	$EnergyPov = \frac{Energy\ cost}{Family\ Income}$	Share of households' expenditure on electricity, gas and other housing fuels, available from Eurostat: https://ec.europa.eu/eurostat/web/products-datasets/-/tec00134
CO_2 emissions reduction	**CO_2savings**	%	Percentage of CO2 emissions saved due to the implementation of the circular economy enabled measures	$CO_2savings = \frac{GWP_{baseline} - GWP}{GWP_{baseline}} \cdot 100$ $CO_2savings = \left(1 - \frac{GWP}{GWP_{baseline}}\right) \cdot 100$	Used widely and justified in several sources. For instance, Nubholz et. al (2019). Circular building materials: Carbon saving potential and the role of business model innovation and public policy. https://doi.org/10.1016/j.resconrec.2018.10.036
Global Warming Potential or Carbon Footprint	**GWP**	tCO_2eq	Total CO_2 emissions caused by an individual, event, organization, or product (in HOUSEFUL case, the building retrofitting action), expressed as carbon dioxide equivalent. This requires the inclusion of indirect emissions, accountable by means of a Life Cycle Assessment, if possible, or similar procedure	**GWP from LCA software (SimaPro, GaBi, ...)**	Carbon Trust: https://www.carbontrust.com/home/ Ecoinvent: https://www.ecoinvent.org/
Economic Assessment Indicators: - Life Cycle Costing - Net present value (Materials)	**LCC NPV**	**€ % Years**	Total Life Cycle costs, obtained from a LCC analysis, including all externalities, both positive and negative NPV (Net Present Value) is an investment term that represents the difference between the present (and/or discounted) value of cash flow in the future and the present value of the investment and any cash flow that may accumulate in the future. Basically, it represents the net result of a multiyear investment.	$LCC\,[€] = CAPEX + OPEX + Renovation\ Costs + Disposal\ Costs - Residual\ Value - External\ benefits + External\ Costs$ $ROI[\%] = \frac{Net\ Income\ - Initial\ Investment}{Initial\ Invesment}$ $PB[years] = \frac{Initial\ Investment}{\sum_{i=0}^{N} \frac{R_{t,i}}{(1+DRY)^i}}$ $NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$ **where:** R_t = net cash inflow-outflows during a single period t i = discount rate or return that could be earned in alternative t = number of time periods	LCC: https://www.oneclicklca.com/building-life-cycle-costing-in-construction/ NPV: https://www.investopedia.com/terms/n/npv.asp

Table 4.1: HOUSEFUL KPIs

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