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Circular economy and life cycle perspective

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WP8 LCA/LCC/TE analysis of Demo Cases

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EXECUTIVE SUMMARY

WP:	WP8 - LCA/LCC/TE analysis of Demo Cases (M1-M48)
Task:	8.1 - Overview of methodologies for the assessment of Circular Economy and its effect in marine litter reduction (M1-M9)
Title:	Circular Economy and life cycle perspective

This deliverable contains a detailed review of literature related to different aspects addressed within a circular economy approach. Concretely, three different aspects are addressed in this report:

The first one comprises a literature review of the concept of value chain, circular economy, life cycle thinking and available methodologies to measure the integration of those concepts into different sectors related to plastic. Besides, a review of publications including circular economy assessment methods is also included in this deliverable. However, due to the novelty of this approach, it was observed that there is not a homogeneous methodology to evaluate the circularity and sustainability of a system. In fact, a deeper research about what kind of indicators are used to evaluate ecoefficiency, industrial symbiosis, sustainability and circular economy has been performed. This review was a useful activity to determine what parameters are evaluated in other studies related to circularity and this way, selecting the most appropriated indicators (KPIs) to be used during the evaluation of the innovations performed during the polynSPIRE project development.

The second aspect addressed in this deliverable is related to the current problematic of plastic waste leakage into marine environment. An overview about the problem of plastics leaking to the ocean has been performed in a global scale, studying the sources, volumes, pathways and trends. Besides, in line with the above, those indicators that can be applied to evaluate the impacts caused by marine litter, as well as the methodologies used by different authors, have been reported.

Finally, the third aspect addresses in this document aims at identifying the most relevant best practices that are recommended to be applied in the plastic sector according to the guidelines published by the European Commission, as well as other tools currently used to determine and improve the circularity of processes.

To sum up, the objective of this deliverable is to present an overview of the current situation of the plastic sector and the progress made so far on the way to the development of a more sustainable economy. The challenges addressed within the polynSPIRE project will aim at addressing some of the problems identified in this document by improving the circularity of plastics and reducing the consumption of raw materials based on fossil sources.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABS – Acrylonitrile Butadiene Styrene
AIRIS – Annual Indicator Report Series
BAT – Best Available Techniques
BPA – Bisphenol A
CAPEX – Capital Cost
CE – Circular Economy
CEIP – Circular Economy Indicator prototype
CEIS – Circular Economy Indicator System
CET – Circular Economy Toolkit
CPI – Circular Performance Indicator
CPSI – Composite Sustainable Development Index
CSI – Core Set of Indicators
D – Deliverable
DC – Demo Cases
DoA – Description of Action
EAP – Environment Action Program
EASAC – European Academies' Science Advisory Council
EBI – European Benchmark Indicator
EC – European Commission
ECC – Embodied Carbon Cost
ECFI – Energy Consumption Financial Impact
EDCs – Endocrine Disrupting Chemicals
EEA – European Environmental Agency
EEI – Eco-efficiency Indicators
E-LCA – Environmental Life Cycle Assessment
EMF – Ellen McArthur Foundation
EMS – Environmental Management System
EPR – Environmental policy review
EPSM – Environmental performance strategy map
ETV – Environmental Technology Verification
EU – European Union
EUPC – European Plastics Converters
FP7 – Framework Programme 7
GA – General Assembly
GDP – Gross Domestic Product
GHG – Green House Gases
H2020 – Horizon 2020 The EU Framework Programme for Research and Innovation
HIPS – High Impact Polystyrene
IRR – Internal Rate of Return
ISI – Industrial Symbiosis Indicators
KPIs – Key Performance Indicators

LC – Life Cycle
LCA – Life Cycle Assessment
LCC – Life Cycle Costing
LDAR – Leak Detection And Repair
LDFS – Landfill Diversion Financial Saving
LFI – Linear Flow Index
M&M – Monitoring and Maintenance
MCI – Material Circularity Indicator
MIPS – Material input per unit service
MRS – Material Reutilization Score
NCI – Network Connectivity Index
NPV – Net present value
OECD – Organisation for Economic Co-operation and Development
OPEX – Operational cost
PA – Polyamide
PET – Polyethylene terephthalate
PH – Potential Hazard
PP – Payback Period
PU – Polyurethane
RACER – Relevant, Accepted, Credible, Easy, Robust
RBR – Recyclability Benefit Rate
RCRB – Recycled Content Benefit Rate
RIR – Recycling Input Rate
ROI – Return on investment
SAN – Styrene Acrylonitrile
SDGIs – Sustainable Development Indicators
SDGs – Sustainable Development Goals
SETAC – Society of Environmental Toxicology and Chemistry
S-LCA – Social Life Cycle Assessment
SMART – Specific, Measurable, Attainable, Relevant, Time-bound
SRM – Secondary raw material
TE – Thermo-Economic
TFI – Transportation Financial Impact
UNEP – United Nations Environment Programme
UV – Ultraviolet
VC – Value Chain
VCA – Value Chain Analysis
VMFS – Virgin Materials Financial Saving
VRE – Value based Resource Efficiency
WP – Work package

1 INTRODUCTION AND OBJECTIVES

This deliverable was performed within the work package 8 activities, corresponding to the task 8.1: "overview of methodologies for the assessment of Circular Economy and its effect in marine litter reduction". The overall objective of WP8, within the polynSPIRE project, is to design a methodology to address and optimise the environmental performance of the recycling scheme taking into account the whole value chain for the targeted waste streams. This will be achieved through the specific objectives below:

- To review the existing background for the assessment of Circular Economy focused on plastic recycling and valorisation.
- To analyse the impact of plastic recycling on marine litter.
- To perform a comprehensive description of the reference conditions for each value chain to determine the potential saving.
- To perform Life Cycle (LCA/LCC) and Thermo-economic (TE) studies of the current value chains (current environmental and economic impacts for the currently used technologies and its implications alongside the whole value chain).
- To perform LCA/LCC and TE analysis of the implementation of innovative recycling technologies and their implications alongside the new circular value chains.
- To create a dynamic model of the process as the basis of the neural network implementation

As a first step on this roadmap, Task 8.1 is devoted to conduct an overview of methodologies for the assessment of Circular Economy and its effect in marine litter reduction. With this aim, the participant partners, namely CIRCE and CSM SPA, will closely collaborate in the task as defined in the DoA. In this vein, the first two specific objectives of the WP8 are addressed in D8.1, resulting from task 8.1:

- Establishing a baseline/background on value chain scenario assessments through a detailed review of literature focused on circular economy assessment and on sustainability indicators.
- Performing an overview of the current state of the art regarding methodologies used to evaluate the impact of marine leakage.

The deliverable is divided into three different parts. Firstly, an overview of principal methodologies and indicators to circular economy assessment will be made in order to establish a background on value chain scenario assessment. The second part will study the principal impacts of marine litter, especially plastics, as well as the methodologies of indicators used to evaluate them. Finally, the best practices and methods available in plastic waste and circular economy will be identified.

Both objectives will be accompanied by a dedicated research on reference EU FP7 and H2020 projects, to set the basis of previous developments in order to take a step further in improving sustainability from a circular perspective and reduced marine litter.

All the above will allow to explore the current situation of different plastics value chains in order to stablish the baseline from where to define the approach that will be applied in the rest of the tasks involved in WP8 regarding the application of a life cycle perspective.

2 METHODOLOGY

The work presented in this deliverable aims at achieving three objectives clearly defined. All of them are included within the activities performed in task 8.1. The mentioned objectives are:

1. Establishing a baseline/background on value chain scenario assessments through a detailed review of literature focused on circular economy assessments and on indicators used in those studies.
2. Performing an overview of the methodology used to evaluate the impact of marine leakage.
3. Performing an overview of the best practices currently available in plastic waste and circular economy systems.

2.1 METHODOLOGY FOR OBJECTIVE 1

Objective 1: "Establishing a baseline/background on value chain scenario assessments through a detailed review of literature focused on circular economy assessments and on the indicators used in those studies."

The first objective addressed in this deliverable consists of performing a literature review about the concept of value chain, circular economy, life cycle thinking and available methodologies to measure the integration of those concepts into different sectors related to plastic. Furthermore, existing practices related to circular economy assessments will be analysed, as well as its potential replication under the methodology to be applied in polynSPIRE project. Additionally, in order to go deeper into those assessment methods, a review of the most common indicators currently used to evaluate ecoefficiency, industrial symbiosis, sustainability and integration of circular economy will been set, especially those involved in plastic waste processes.

In short, the following activities will be conducted

- 1. Literature Review
  - Review of CE systems and methodologies currently existing to assess plastic value chains.
  - Summary of potential impacts of waste plastics, especially for PA and PU wastes.
  - LCA approach as a tool to assess circular economy systems

- 2. Stablish an overview of KPI referred to circular economy aspects
  - Recompilation of parameters related to ecoefficiency.
  - Recompilation of parameters related to sustainability.
  - Recompilation of parameters related to circular economy itself.

2.2 METHODOLOGY FOR OBJECTIVE 2

Objective 2: "Performing an overview of the methodology used to evaluate the impact of marine leakage."

This objective entails the mapping of relevant publication (scientific publications, projects, etc.) related to marine litter, especially plastics. An overview will be made about the problem of plastics leaking to the ocean in a global scale, studying the sources, volumes, pathways and trends. Then, different potential impacts (on biodiversity, human health, and economic activities) of plastic products that end up in the

ocean will be identified. Additionally, methodologies, standards or potential key performance indicators (KPI) to assess the marine plastics impacts will be revised.

Similar to the objective 1, three steps were conducted to achieve the above:

- 1. Background and current situation.
  - Review of literature focused on the current problem of marine litter in order to study the sources, volumes, pathways and trends of plastics leaking to the ocean.
- 2. Study of marine litter impacts.
  - Overview of different impacts that marine plastics have in marine biodiversity, human health and economic activities
- 3. Identification of relevant methodologies or potential Key Performance Indicators (KPIs) to evaluate marine leakage impacts.
  - Overview and classification of existing methodologies and indicators to asses marine leakage impacts.

2.3 METHODOLOGY FOR OBJECTIVE 3

Objective 3: "Performing an overview of the best practices currently available in plastic waste and circular economy systems"

The third objective of this deliverable is to identify the most relevant best practices that are recommended to be applied in the plastic sector according to the guidelines published by the European Commission. Besides, other existing tools to evaluate how circular a system is and this way, to stablish different strategies to improve the circularity of a process will be identified and described, highlighting the advantages and disadvantages associated with the use of each one. Finally, a detailed review of European FP7 and H2020 projects related to circular economy systems and plastic marine leakage impact studies will be also explored.

- 1. Identification of best practices related to polymers production, waste incineration and waste treatment.
- 2. Identification and analysis of available tool to measure product circularity.
- 3. Identification of circular economy projects and tools from FP7 and H2020 programmes.
- 4. Conclusive guidelines about plastic waste recovery, recycling and valorisation and also, recommendable methodologies to be applied to polynSPIRE project.

3 CIRCULAR ECONOMY ASSESSMENT

3.1 LITERATURE REVIEW

3.1.1 Value chain. Concept and analysis

The concept of value chain refers to all the activities and services that bring a product or a service from its conception to its end use in a particular industry. In other words, a value chain considers all the activities involved from input supply to production, processing, wholesale and finally, retail. It is called so because value is being added to the product of service at each step [1]. This term was created by Porter in 1985 and defined as a "set of activities that are performed to design, produce and market, deliver and support its product" [2]. By disaggregating a firm into its strategically relevant activities, it is possible to understand the behaviour of costs and the existing and potential sources of differentiation. According to Porter, the mentioned activities can be classified into primary activities, which are those directly involved in creating and adding value to the product, and support activities, which aims at providing assistance to improve the performance of the primary activities.

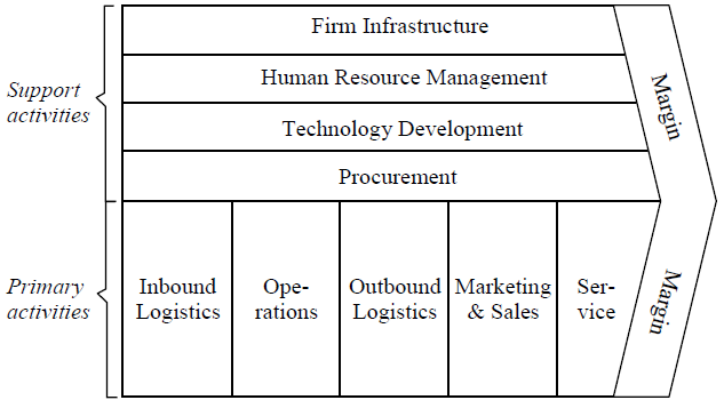

Figure 1. Value chain by Porter [2]

In this light, Value Chain Analysis (VCA) is the process of identifying the firm's competitive position and how it can be sustained and improved. Mapping the value chain is a useful tool to determine the external players whose activities can influence in a company's success. The principal stages of a value chain analysis can be summarized in the following six stages [3][4]:

1. Identification of the value chain activities and disaggregation of the firm into separated activities.
2. Establishment of the relative importance of the different activities in the total cost of the product.
3. Comparation of costs by activities and identification of the critical ones.
4. Identification of cost drivers (activities that are a source of competitive advantage).
5. Identification of linkages and interrelationships in the value chain.
6. Identification of opportunities for reducing costs and/or improving value.

3.1.2 Plastic sector. Current situation and expected evolution

The history of manufactured plastics goes back more than 100 years. However, plastics are relatively modern compared to other materials used in the industry. Their development and use over the years, has enabled society to make huge technological advances.

Although plastics are thought as a modern human invention, there have always been "natural polymers". They can be found, for example, in different nature elements (such as amber, latex, cellulose, honey) or in molecules of organisms (such as proteins, DNA, RNA). [5] In 1907, the Nobel Prize in Chemistry Leo Hendrick Baekeland (1863-1944) created the first synthetic plastic substance, the Bakelite. Half a century later, in the fifties, these synthetic fibres begin to be produced massively and to be introduced in the market. In the early twentieth century, there was a rapid development of new plastics and commercial production was accelerated during the World War II [6].

Global plastics production has increased exponentially since 1950. At that time, there were 2.5 billion people on Earth and the global production of plastic was 1.5 million tonnes. Today there are more than 7 billion people and plastic production reaches around 350 million tonnes annually [7][8].

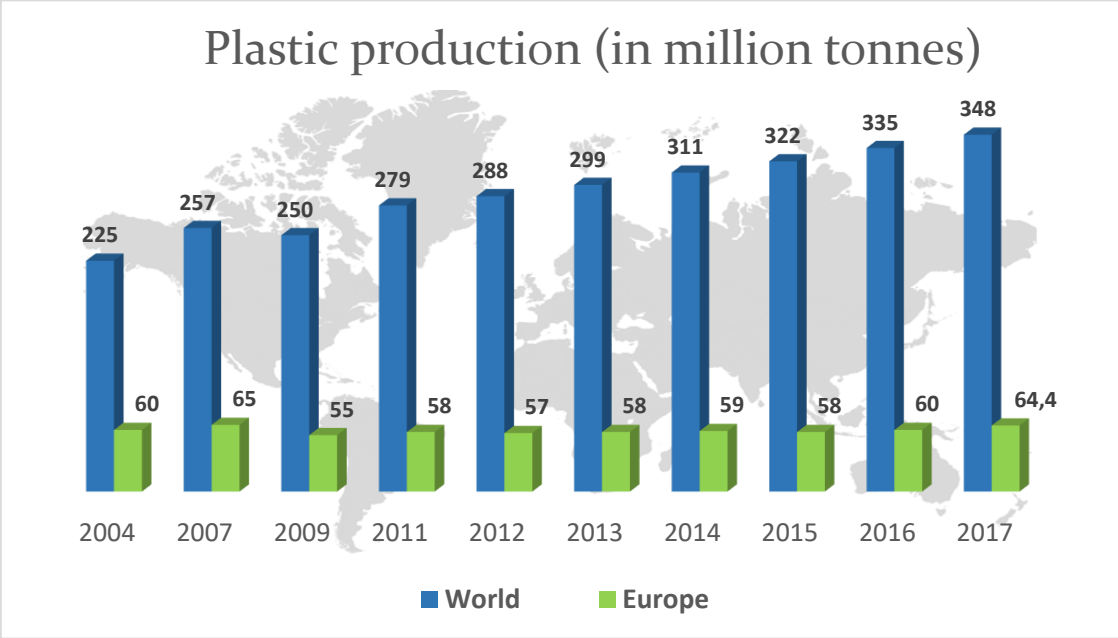

Figure 2. Worldwide plastic production. Own preparation based on information of [8]

Although plastic is a familiar material in everyday life, many people do not know where plastic comes from, or even how to define what plastic is.

“Plastics are a group of materials, either synthetic or naturally occurring, that may be shaped when soft and then hardened to retain the given shape. Plastics are polymers. A polymer is a substance made of many repeating units. The word polymer comes from two Greek words: poly, meaning many, and meros, meaning parts or units. A polymer can be thought of as a chain in which each link is the “mer,” or monomer (single unit). The chain is made by joining, or polymerizing, at least 1,000 links together” [9].

Most of plastics (over 99%) are composed of hydrocarbons derived from fossil fuel feedstocks. Oil and natural gas are the major raw materials used to manufacture plastics. The plastics production process often begins by treating components of crude oil or natural gas in a "cracking process." This process results in the conversion of these components into hydrocarbon monomers (such as ethylene, propylene). After that, those monomers are linked together into long chains to form a polymer backbone [10].

During the manufacturing process, a wide range of additives (including fillers, plasticizers, flame retardants, UV and thermal stabilizers, and antimicrobial and colouring agents) may be added to the polymers. As a result, a large variety of plastics can be produced with highly versatile properties (including strength, durability, light weight, thermal and electrical insulation, and barrier capabilities) and many forms (such as adhesives, foams, fibres, and rigid or flexible solids, including films) [6].

Thanks to their broad range of characteristics and their low price, plastics are used in many applications and their industrial demand is growing every year. Some researchers have described this period as the "Age of Plastics", to the point where nowadays, life without them is almost unthinkable [7].

Plastics are very important in the world economy and they are used in many sectors, including food and water packaging, consumer products like textiles and clothing, electrical and electronic devices, life-saving advanced medical equipment and construction materials. In Europe, the largest plastic demand corresponds to packaging sector (around 40%), building and construction sector (around 20%) and automotive sector (around 10 %) [8].

The current plastics economy presents some inexorable drawbacks that are becoming more apparent by the day. That is why a new plastics economy aligned with the principles of the circular economy is necessary to enhance system effectiveness to achieve better economic and environmental outcomes while continuing to harness the many benefits of plastic. The objective is going towards a more sustainable plastic industry, where design and production respect the needs of reuse, repair, and recycling, bring growth and jobs to Europe and help reducing EU's greenhouse gas emissions and dependence on imported fossil fuels [11].

3.1.3 Value chain in plastic waste sector

Plastic materials have a huge potential even after the end of its useful lifetime due to its recyclability. Depending on the quality of the recovered waste fraction, plastic still can retain value and functional properties and this way, contribute to the efforts of the European Union towards a circular economy.

Globally, millions of tonnes of waste are generated annually. It is estimated that on an average, a developing country generates nearly 100,000 metric tonnes of solid waste per day, of which around 40% is recyclable [12]. In many metropolitan cities of developing countries, the amount of plastic waste has grown up to a 20% of the total amount of the household waste [13]. Landfills in many developing countries are filling up rapidly and many households, mainly in the poor neighbourhoods of cities, still burn their waste directly, generating toxic fumes from the plastics in the waste. Besides, according to the European Commission, as much as 10 million tonnes of litter, mostly plastic, end up in the world's seas and oceans, broken into micro plastic, the so-called '*plastic soup*' [14].

Plastic production in the EU is expected to increase at a rate of 5% annually. While only 24% of plastic waste is recycled, close to 50% is landfilled, and the rest is incinerated. In the EC Communication [15] for increasing recycling and abandoning landfilling are emphasised to improve plastic waste management. After a first-use cycle, the recycling rate for plastics is far below the global recycling rates for paper (58%) and iron/steel (70–90%), and only 5% of material value is retained for a subsequent use [16]. A staggering rate of plastic escapes from collection systems, generating significant economic costs. Additionally,

recycled plastics are mostly recycled into lower-value applications, that are not again recyclable after use. In a recent study of the Ellen McArthur Foundation [16], it was published that 95 % of plastic packaging material is lost to the economy after a short first use. In fact, only 14 % of the plastic packaging is collected, , and after its sorting and reprocessing, only 5 % of material value is retained for a subsequent use.

In order to address the above problematic, a CE thinking is getting stronger. The overarching vision of the new plastics economy is that plastics never become waste: rather, they re-enter into the economy as valuable technical or biological nutrients. Under this approach, negative externalities associated with plastics and plastic leakage would be significantly reduced, and plastics would be decoupled from fossil feedstocks. In this sense, the first step to apply this innovative approach is to know in detail the value chain of each kind of plastic and product.

There are many study cases in the grey literature about the application of VCA in different sectors [17]–[19], but not in indexed scientific journals due to the novelty of this thinking. Among the few studies that could be found in this kind of publications, Jaliot et al [20] applied the VCA to the polyethylene terephthalate (PET) recycling process in Cairo, Egypt. To this end, the first stage consisted in mapping the value chain (Figure 3.). In this study case, recovered PET from plastic bottles is used to make textile fibres. Then, it was determined the value added at each step of the value chain, considering the selling prices of the product after each processing as well as the losses. After this, a set of indicators were defined to address the challenges under consideration. These indicators were classified into three categories depending on its nature: connections in the value chain, waste valorisation and enabling environment. Finally, a dynamic system map was performed, showing how each indicator influences the stocks within the value chain, the flow variables and other indicators. Performing this analysis was a significant and powerful addition to the available analytical tools aimed to improve the position of the recycling sector. Moreover, it contributed to targeting the needs for interventions in those steps of the value chain with the greatest impact in the overall system.

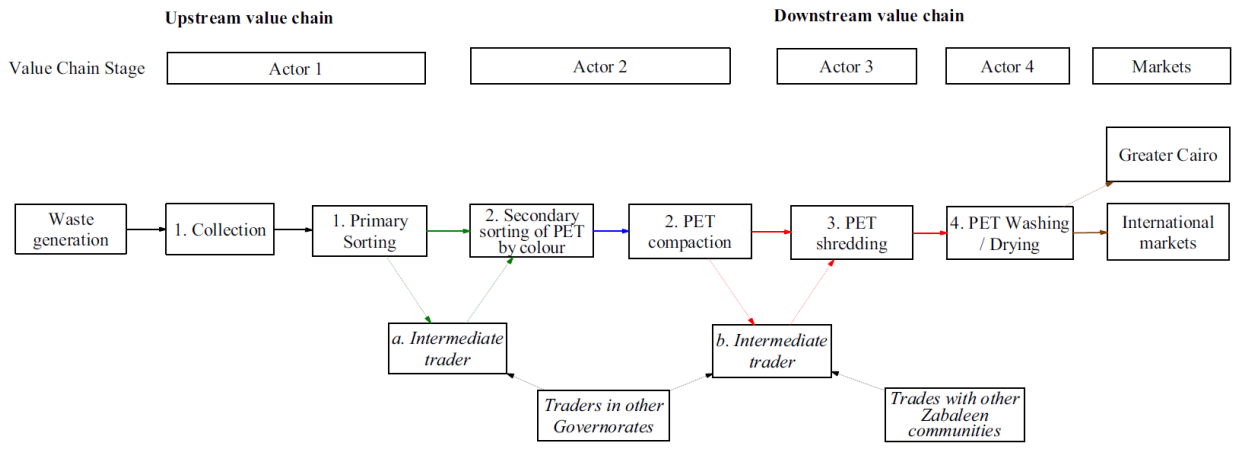

Figure 3. Map of the PET value chain in the Zabaleen community, Cairo [20]

According to Simon [21], one of the main problems in the plastic circular economy arises if a particular type of plastic waste is contaminated by another one, leading to a drastic quality drop of the secondary material. Some industrial branches demand high standards of raw material quality and here, the acceptance of recycled plastic is rather low. The quality and composition of plastic is intended for vary in each specific

application. For example, plastic applicable to food contact must be “high-quality” plastic. On the other hand, low-quality plastic can be used in applications with less strict requirements in relation to chemical composition or migration, such as electrical and electronic equipment, non-food packaging, etc. [22].

In this light, Milios et al [23] performed a study to approach the analysis of the plastics waste market from a value chain perspective, based on the general plastic waste recycling chain value depicted in Figure 4.. In that study, they identified that some barriers in the recycling market plastic are: lack of demand by producers due to price considerations, lack of traceability and transparency in value chain transactions of recyclables, and general design deficiencies when it comes to the recyclability of products.

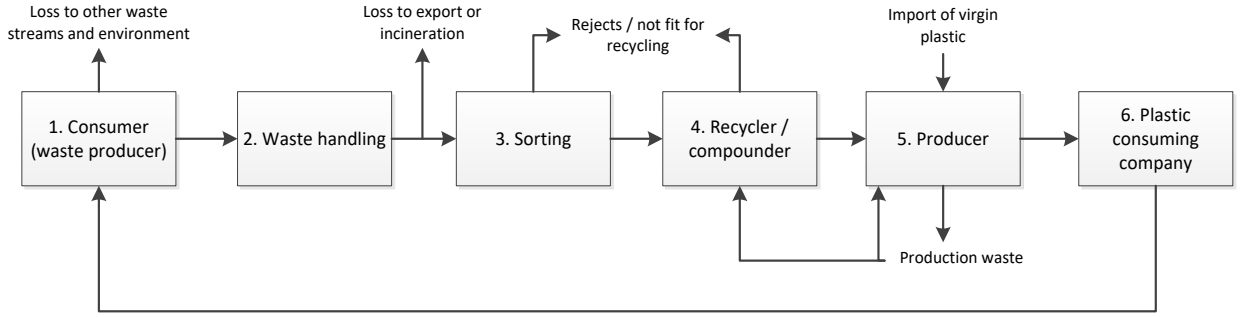

Figure 4. Plastic waste recycling value chain [23]

To sum up, even though the social awareness about the environment is growing and more recycled plastic products are being demanded, there is still a long way to go and many barriers to overcome before we can achieve a real sustainable plastic production based on the improvement of the complete value chain systems.

3.1.4 Circular economy. Definition and methodologies

The Circular Economy (CE) is an industrial system that is restorative and regenerative by design. It rests on three main principles: preserving and enhancing natural capital, optimising resource yields, and fostering system effectiveness [16]. Unlike linear economy, CE aims to recover and valorise wastes in order to allow using materials back into the supply chain. This way, the need for raw material is reduced, as well as the waste disposal.

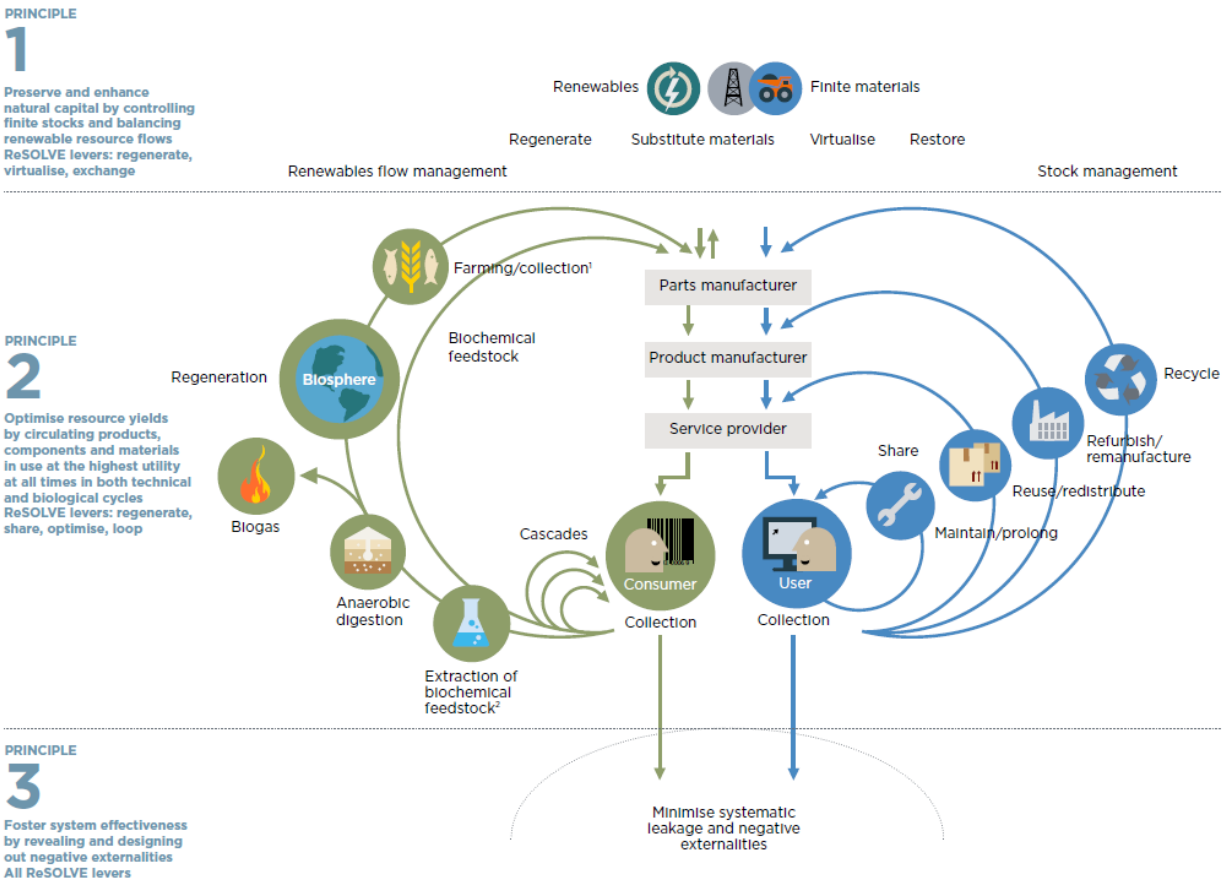

Figure 5. Outline of a circular economy [16]

According to the EU Action Plan for the CE, "*the transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy*" [24].

As stated by the Ellen McArthur Foundation, there are no official or recognized indicators methods or tools to measure the company performance in the shift from a linear economic model to a more circular one and neither tools for supporting such a transition [25].

In order to define an effective measurement process of the CE adoption, a four-level framework was defined by Elia et. al. (2016) [26]:

1. **Process to monitor:** This level defines the process whose performances must be measured to evaluate how circular is the overall system in analysis. This study comprises a characterization of the material inputs of the value chain system, the design, the production, the consumption, and the end-of-life resource management.
2. **Actions involved:** In order to support the adoption of the CE paradigm, four categories of actions were proposed by Ellen McArthur Foundation (2013) [27].
    a. Circular product design and production: e.g, eco-design methods oriented to facilitate product re-use, refurbishment and recycling, design of products and processes with less hazardous substances.

   b. Business models: diffusion of new models such as new collaborative consumption tools based on a wider diffusion or consumer-to-consumer channels.
   c. Cascade/reverse skills: actions focused on supporting the circular economy with innovations technologies for high quality recycling.
   d. Cross cycle and cross sector collaboration: actions focused on increasing the collaboration between the actors of the value chain.
3. **Requirements to be measured:** In this stage, five main categories were stablished from the EEA report [28]:
   a. Reducing input and use of natural resources. The aim of these requirements is to preserve the natural resources with an effective use of raw materials, water and energy.
   b. Reducing emission levels. This refers to direct and indirect emissions.
   c. Reducing valuable materials losses. This aims to recover and recycle products in order to reduce the incineration and landfilling processes.
   d. Increasing share of renewable and recyclable resources. The goal is to use less raw materials and more sustainable sourcing.
   e. Increasing the value durability of products. Extension of the products lifetime by means of the re-using or recycling of products.
4. **Fields of intervention:** three implementation levels can be differentiated: the micro level – referring to single companies or customers-, the meso level - meaning eco industrial parks- and the macro level - from cities to nations.

Besides the description of the methodology explained above, it is also very relevant to evaluate the procedures to measure the environmental effectiveness of the CE strategies. Elia et al. [26] perform a literature review of all the existing methodologies classified according to two different criteria: the method typology, this is, if it is based on a single synthetic indicator or on a set of multiple indicators, and the parameters to be measured, following a four categories classification (Figure 6.). By following the progress of some indicators defined in each methodology, the adoption of CE paradigm can be measured. The study of those indicators will be later addressed in this deliverable.

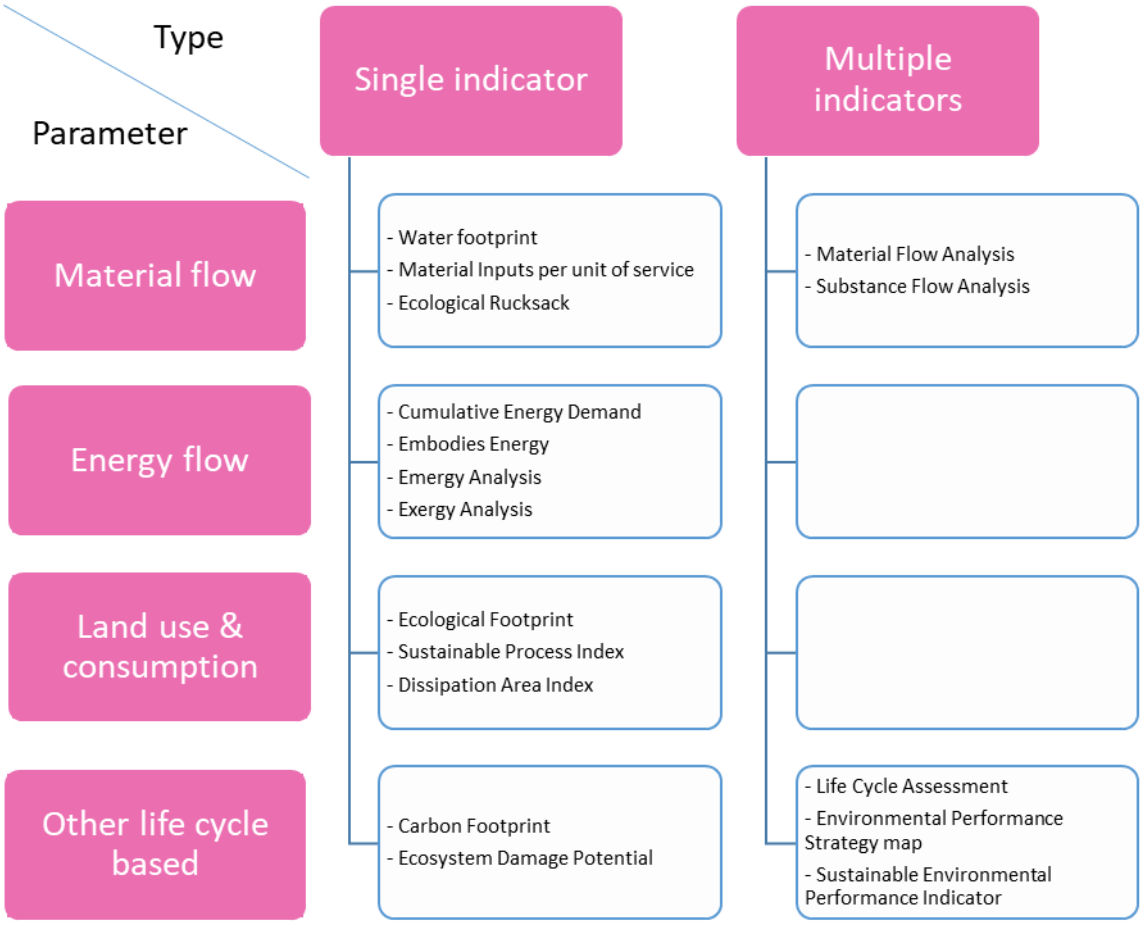

Figure 6. The proposed taxonomy of index-based methodologies adapted from [26].

Finally, in the study performed by Elia et al 2017 [26], a guideline to support both researchers and practitioners in evaluating the effectiveness of a CE strategy has been designed (Figure 7.). After identifying the process to monitor, the activities implemented and the requirements to measure, it must be chosen an appropriated methodology to assess the circularity of a strategy based on the classification shown in Figure 6.. As some examples, the adoption of a CE strategy in a company could be based on increasing recycling rates or orientated to the re-use of its own waste thus reducing its emission levels. The most appropriated indicators should be selected in each case and this way, facilitate the comparison and progress analyses.

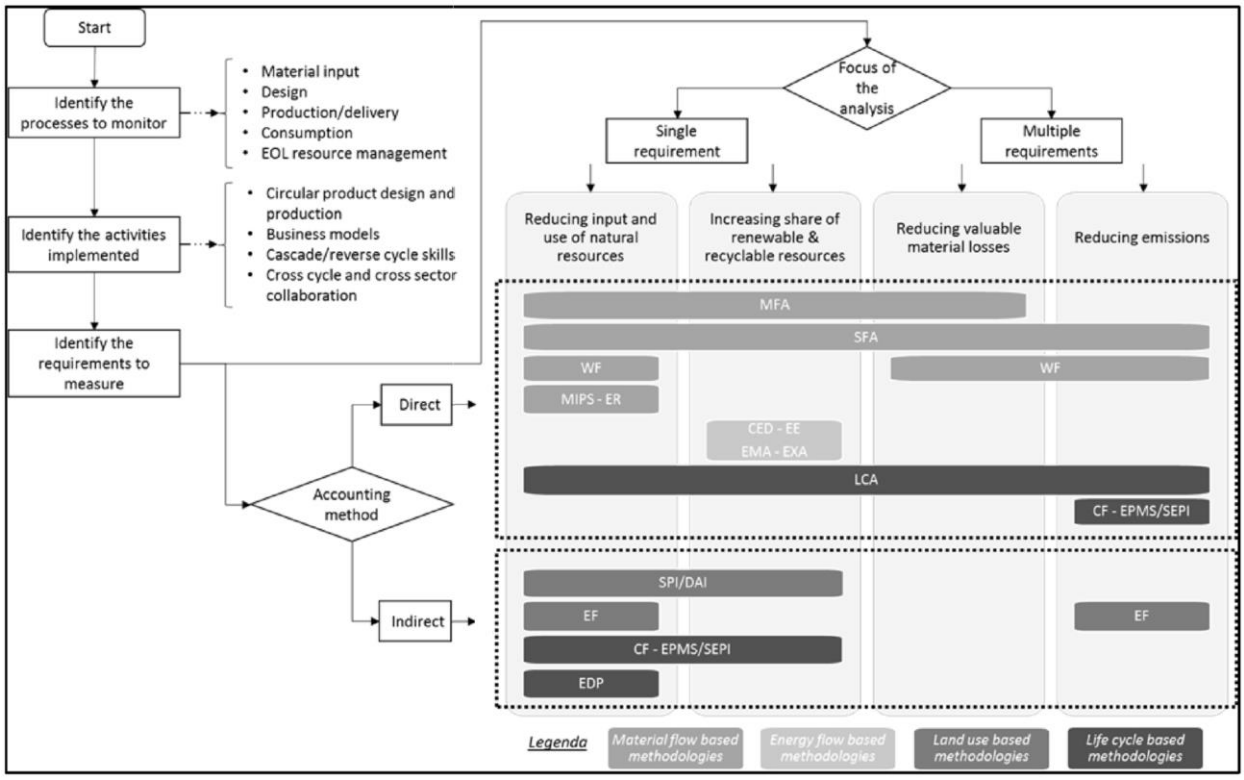

Figure 7. Critical steps in the assessment of a CE strategy [26]

In the study published by Saidani et al. (2017) [29], three existing tools, available online for free, to measure the product performance in a context of CE are evaluated. These tools allow having qualitative information and overview of in which areas a product could be improved to be integrated into a more circular value chain: These tools are:

- Material Circular Indicator (MCI) [25]: It aims at helping companies to measure their transition towards a circular economy.
- Circular Economy Toolkit (CET) [30]: It is an assessment tool to identify potential improvement of products' circularity.
- Circular Economy Indicator Prototype (CEIP) [31]: The CEIP aims at evaluating product performance in the context of circular economy.

A more detailed explanation of these tools can be found in section 6.2 of this deliverable. Furthermore, two additional tools were developed by Kalmykova et al. (2018) [32] to facilitate circular economy design. The first is a CE strategies database, which includes 45 CE strategies that are applicable to different parts of the value chain. The second is a CE implementation database, which includes over 100 case studies categorized by their scope, parts of the value chain that are involved, as well as by the used strategy and implementation level.

So, as seen with this brief literature review, the evaluation of the CE application is assessed by means of a set of indicators classified under different categories, as well as by a set of CE indexes which aims to combine some of them and provide an aggregate measure of circularity. A breakdown of these indicators is contended in section 3.2.2 of this deliverable.

3.1.5 Life cycle approach as a tool to assess circular economy systems

According to the definition given by the Life Cycle Initiative [33], the life cycle thinking is a way of operating that takes into account the economic, environmental and social consequences of a product or a process over its entire life cycle. In this light, this thinking becomes a useful tool for the decisions-makers considering the impacts incurred during the whole lifetime of the product, as well as the end-of-life scenarios. Besides, from a social and environmental viewpoint, the manufacturer thinks about the potential consequences of his actions before they happen and this way, the decisions taken can also be focused to maximize the environmental benefits.

One key characteristic of the life cycle approach is that it requires companies to move away from just looking at their own operations and to look at what is happening in their value chain (upstream and downstream operations that are outside the company's direct control) [34]. In this light, the main objectives of the life cycle thinking are to reduce a resource use as well as to improve its socio-economic performance through its life cycle. Everything that is created goes through a series of life cycle stages, from the material extraction to the end of life. The scientific process of understanding what impacts are incurred as a consequence of the energy and materials flows involved through the value chain is called Life Cycle Assessment (LCA). This is a complex and strongly detailed process, which aims at evaluating all the needed inputs of a product life cycle and transforming that information into environmental indicators. There are many indicators related to different problematics such as human health, damage to ecosystems, resource availability, etc.

LCA is a standardized tool by the International Organization of Standardization (ISO 14040/14044). As introduced before, LCA is a compilation and evaluation of the inputs, outputs and other interventions and the current or potential environmental aspects and impacts (e.g., use of resources and the environmental consequences of releases) throughout a product's life cycle – from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e., "cradle to grave" perspective). This way, a LCA can assist [34]:

- Identifying opportunities to improve the environmental performance of products at various points of their life cycle.
- Informing decision-makers in industry, government or non-governmental organizations (e.g., for the purposes of strategic planning, priority setting, and product or process design or redesign).
- Selecting relevant indicators of environmental performance, including measurement techniques.
- Marketing (e.g., implementing an eco-labelling scheme, making an environmental claim, or producing an environmental product declaration).

Besides the environmental framework, the life cycle approach provides guidelines to help with the integration of the three dimensions of sustainability – environmental, economic and social – to avoid shifting impacts from one dimension to another [35]. This way, three existing frameworks can be differentiated within this approach: Environmental Life Cycle Assessment (E-LCA), or how is commonly called, just Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA).

The LCC is the analysis of all the costs (direct and indirect, variable and fixed) attributable to a product/service from the beginning of the idea conception to the end of its useful life and also during the end-of-life scenarios, by or for any agent associated with any phase of its life cycle (provider, producer, consumer, etc). During the design stage, a detailed knowledge of all the costs with influence on any of the

actors of the product life cycle allows making decisions comprising most of the economic items that would be ignored in other kinds of economic evaluation. This way, the LCC analysis facilitates the integration of the economic and environmental approaches as pillar values, developing innovative business models based on the study of the product or service as a single system throughout its life cycle and as a consequence, generating new consumption habits. To do this, it is necessary to quantify the relationship between the economic and environmental optimization of a product or service in order to determine how the economic activities have influence on the environmental activities to create value, and vice versa.

The last of the frameworks mentioned before is the S-LCA. This is a social impact assessment tool whose objective is to analyse the social and socio-economic aspects of a product / service and their potential impacts (positive or negative) during its life cycle. This study can be applied independently or in combination with a LCA. An S-LCA includes the social effects both in the workers and in the community where the product takes place or repercussion in any stage of its life cycle. On this sense, the UNEP/SETAC working group have identified three dimensions or causes of social impacts [36]:

- *Behaviour*: social impacts are those caused by a specific behaviour or decision, such as forbidding employees to form unions and allowing illegal child labour.
- *Socio-economic processes*: social impacts are the downstream effect of socio-economic decisions, e.g. an investment decision in a sector to build infrastructure in a community.
- *Capital (human, social, cultural)*: social impacts related to the original context (attributes possessed by an individual, a group, a society e.g., education level).

In summary, life cycle studies are a useful tool to assess circular and complex systems since it comprises the evaluation of all the stages involved from the first stages related to the extraction and transformation of raw materials to the end-of-life scenarios that could be applied to one product after the end of its useful life. Acquiring a deep knowledge of all these stages will be a useful tool to optimize the value chain as well as to identify the critical stages in which the environmental impacts should be reduced. In addition, the application of the life cycle thinking in any of the points of the value chain allows a company to move away from just handling their own operations to see what is happening in other upstream and downstream processes. This way, it is possible to evaluate the effect that one decision taken in any of the points of the value chain will have on the remaining processes performed by the actors of the same value chain and generate real environmental improvements for the welfare of the society.

3.2 KEY PERFORMANCE INDICATORS REFERRED TO CIRCULAR ECONOMY

The aim of this section is to present a collection of indicators that are currently used to assess how sustainable and circular a system is. To do this, a deep literature review was performed, and the indicators found have been classified into the following categories:

- Ecoefficiency indicators
- Industrial symbiosis indicators
- Sustainability indicators
- Circular economy indicators

3.2.1 KPIs general description and properties

Indicators are used to measure progress and achievements; clarify consistency between activities, outputs and goals; and illustrate legitimacy to all stakeholders. In this line, some of the characteristics applying to performance measures/indicators are: clear, concise, agreed, realistic, reviewed, easy to collect, related to efficiency and effectiveness, understandable, communicable, time scale and quantifiable [37]. To ensure the previous properties, two concepts are widely used to establish the quality that the indicators should have: "SMART" and "RACER".

The pursued outcomes and objectives, and so the performance indicators, are required to meet SMART criteria, (Specific, Measurable, Attainable, Relevant and Time-bound) [38], which are explained in Figure 8..

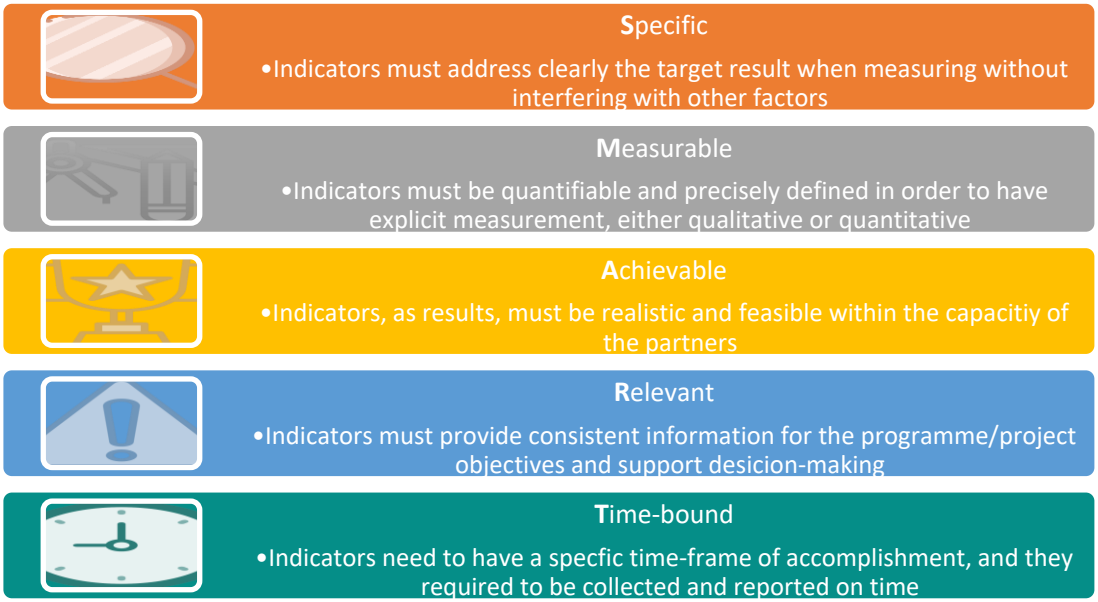

Figure 8. Summary of the characteristics of SMART criteria

In addition, indicators are required to meet RACER criteria (Relevant, Accepted, Credible, Easy and Robust) to fit the requirements to be relevant performance indicators, that is, KPIs. The RACER criteria for identifying useful indicators was developed as part of the European Commission's Impact Assessment Guidelines [39], whose characteristics are explained below according to [40]:

Relevant: closely linked to the objectives to be reached, consider policy support, past and future trends.

Accepted: by staff, management, stakeholders, business/industry, society and other users.

Credible: accessible to non-experts, unambiguous and easy to interpret, transparent and sound.

Easy: feasible to monitor and collect data at reasonable cost, no complex monitoring.

Robust: not easily manipulated, traceable and reproducible; data with good quality, reliability, completeness and representativeness.

3.2.2 Classification of relevant KPIs sets

Based on the nature of polynSPIRE project, the research of KPIs has been focused on aspects related to circularity, environmental and technical performance. It is of the paramount importance to know what the available indicators measure in order to use them properly. Indeed, the identification of the most suited metrics is open, and there is not a consensus creating a methodological framework.

The list of criteria to be determined and then regarded as KPIs, has been created through a systematic literature review of academic, scientific, [29], [39], [41]–[47], policy and strategy [15], [37], [38], [40], [48]–[51] documents. After the review of those documents, the most used and recognized indicators have been listed and classified as a general overview, which will be further customized to the polynSPIRE project in section 5.

Ecoefficiency Indicators

The eco-efficiency represents a key element for promoting fundamental changes in the way societies produce and consume resources, and thus for measuring progress in green growth [48]. The EEI are designed to capture the ecological efficiency of growth by measuring the efficiency of economic activity both in terms of consumption and production (resource-use) and its corresponding environmental impacts. These indicators can be divided also in two several sub-groups:

Environmental impact indicators:

• Resource-used: The European Commission launched the European Raw Materials Initiative in 2008 to address growing concern for resources scarcity, and adopted a strategy document, which classifies the raw material-related indicators. Also, reporting the total volume of water withdrawn by source contributes to an understanding of the overall scale of potential impacts and risks associated with water use. Water consumption accounts for direct and indirect consumption, that is, the sum of all water drawn into the system including surface water, ground water, rainwater, and municipal water supply, for any use.

From the energetic point of view, energy indicators play a crucial part in monitoring the mid-term and long-term shift towards a low-carbon economy in the EU. Key energy-related issues include dependency in fossil fuels, greenhouse gas emissions, energy security and dependency as well as cost. Similarly, exergy is used to measure the quality of the energy. The entropy allows us to measure the irreversibility of exergy, that reduces the work potential of that resource relative to a specified baseline. In this sense, exergy efficiency may be considered as a more accurate measure of energy efficiency, since it accounts for quantity and quality aspects of energy flows. A summary of all these indicators is illustrated in Figure 9.

Raw material consumption	•absolute quantity of raw materials consumed within the system boundary (mass unit)
Raw material intensity	•specific consumed resource per total consumption (mass unit/ mass unit total)
Raw material efficiency	•rate of change in the raw material respect to a reference (%)
Water consumption	•absolute quantity of water consumed within the system boundary (volume)
Water intensity	•specific consumed water per total consumption (volume/volume total)
Water efficiency	•rate of change in the water respect to a reference (%)
Energy/Exergy consumption	•absolute quantity consumed within the system boundary (energy or exergy unit)
Energy/Exergy intensity	•specific consumption over the total, turn over or added value (energy or exergy unit/energy or exergy unit total)
Energy/Exergy efficiency	•rate of change in the energy/exergy intensity respect to a reference (%)

Figure 9. Generic classes of Eco-efficiency indicators related to resource-used

• **Emissions and Waste:** On the one hand, the emissions released to the environment are associated with major global issues, such as ozone depletion, acidification, eutrophication and climate change. Emissions towards air, soil and water represent a great risk and they should be monitored and disaggregated based on the type of activities. Specifically, GHG species in air are converted to carbon dioxide equivalent indicator.

On the other hand, related to waste generation, assessment of wastewater covers both receiving bodies after treatment as well the amount of wastewater recycled or reused as water process, grey water, irrigation, etc… whereas solid waste generation is another basic indicator usually divided into hazardous or non-hazardous wastes. In addition, it is worth mentioning that while by-products indicators are closely related to materials that despite not being the final product, they represent an added value for the same or other plant. The possibility of losing some portion of by-products as residues if processing is required before by-products can be valorised. A summary of all these indicators is illustrated in Figure 10.

GHG emissions	•total emissions, intensity of specific emissions or life cycle indicators (in terms of CO_2 eq)
Emissions to air and soil	•specific account of pollutants, intensity of air emissions, life cycle indicators (kg of pollutant total or per surface)
Wastewater emissions	•total generation, intensity, recycling rates, pollution load in wastewater, life cycle indicators (volume)
Non-hazardous waste	•absolute quantity of waste generated, reported based on EU list of Waste codes, specific waste intensity (mass unit)
Hazardous waste	•absolute quantity of waste generated, reported based on EU list of Waste codes, specific waste intensity (mass unit)
By-products, recyclables and valorisables	•recycling rates, reuse rate, landfill rates, efficiency of valorisation (mass unit)

Figure 10. Generic classes of Eco-efficiency indicators related to Emissions and Waste

• LCA indicators: while the previous indicators quantify the impacts via material and energy flow analyses within the boundaries of the company; LCA indicators use a wider and holistic scope covering the life cycle of the product or process. In other words, LCA studies cover the environmental aspects and potential impacts throughout a product life, from raw material acquisition, via production and use phases, to waste management and wastes released to the environment [52]. The most up-to-date structure of the LCA methodology is proposed by the ISO 14040:2006 guidelines standards [53]. Material/Energy input and outputs can have multiple environmental impacts on different categories based on their possible environmental effects. According to the normative, the indicators are divided in mid-point and end-point. Midpoint impact assessment models reflect the relative potency of the stressors at a common midpoint within the cause-effect chain. Endpoint indicators (human health, ecosystem and resources) are simpler and easier to communicate. However, there are many underlying assumptions and high level of uncertainty during aggregation of midpoint set to endpoint indicators. Some examples of LCA midpoint indicators [54] are given below in Table 1; but the rests of the tasks in WP8 are specifically devoted to LCA and LCC analysis, so a wider approach will be presented in following deliverables.

Table 1. Examples of LCA midpoint indicators and their units from the impact categories of ReCiPe method [54]

Environmental impact category	Units
Climate change	kg CO_2 eq
Ozone depletion potential	kg CFC-11 eq
Terrestrial acidification	kg SO_2 eq
Freshwater eutrophication	kg P eq
Marine eutrophication	kg N eq
Human toxicity	kg 1,4-DB eq
Photochemical oxidant formation	kg NMVOC
Particulate matter formation	kg PM10 eq
Terrestrial ecotoxicity	kg 1,4-DB eq
Freshwater ecotoxicity	kg 1,4-DB eq
Marine ecotoxicity	kg 1,4-DB eq
Ionising radiation	kBq U_{235} eq
Agricultural land occupation	m^2a
Urban land occupation	m^2a
Natural land transformation	m^2
Water depletion	m^3
Metal depletion	kg Fe eq
Fossil depletion	kg oil eq

Other relevant environmental indicators were stated in the year 2009 to monitor recent environmental trends and policy development at EU and national level and progress towards the EU's key environmental goals. The Environmental Policy Review (EPR) was designed with a total of 37 indicators, which can be found in reference [55], and are classified into six environmental themes that are namely; a) climate change and energy, b) nature and biodiversity, c) environment and health, d) natural resources and waste, e) environment and economy, and f) implementation.

Economic output indicators:

The aim is obtaining specific or intensity indicators from total consumption/generation indicators. Different costs can be involved, such as OPEX (operation and maintenance expenditure) [€/year], CAPEX (total investment expenditure) [€] and other financial parameters. The previous indicators can be normalized by using production value (per volume, capacity, unit of production or service), turnover or net added value as denominator combining further basic economic indicators within the life cycle framework. It should be noted that the lifetime and degradation rate of the systems/innovations affects also to some of these indicators. The main general economic indicators are listed in Table 2:

Table 2. Generic economic indicators

Economic indicators	
Turnover	Turnover (revenue) represents the sales made by a company of its products/services expressed in monetary terms in a period, normally annual basis.
Net added value	Net value added is defined as: Net value added = Revenue – Cost of goods and services purchased – Depreciation on tangible assets
CAPEX (Capital cost)	Possible indicators under CAPEX (in monetary units): •Total capital cost •Specific capital cost
OPEX (Operational cost)	Possible indicators under OPEX, (total or specific in monetary units): •Material, water, energy, land-use cost (can be reported separately for primary and secondary or recycled sources) •Labour, maintenance and replacement cost •Waste treatments or disposal costs •Taxes, penalties or other environmental costs
Net present value (NPV)	The Net Present Value, for example, allows comparing alternatives with different cash flows over time. These three following indicators consider both CAPEX and OPEX.
Return on investment (ROI)	Return on investment (ROI) is a conventional economic indicator to be calculated considering actualization over lifetime. The options of public funding and bank loan are to be considered through one or several business models.
Internal rate of return on investments (IRR)	The IRR is defined as the discount rate that makes the present value of the cash inflows equal to the present value of the cash outflows in a capital budgeting analysis, where all future cash flows are discounted to determine their present values.
Payback Period (PP)	It is the length of time required to recover the cost of an investment of an innovation or solution. The payback period of a given investment or project is an important determinant in decision-making, as longer payback periods are typically not desirable.

Life Cycle Costing (LCC)	LCC itself is the only indicator obtained under life cycle costing methodology. It considers all the costs that will be incurred during the lifetime of the product or service, according to Art.61- 2014/24/EU: • Purchase price and all associated costs (delivery, installation, insurance, etc.) • Operating costs, including energy, fuel and water use, spares, and maintenance • End-of-life costs (such as decommissioning or disposal) or residual value (i.e. revenue from sale of product) • Environmental externality costs Conversely to other economic indicators, LCC indicators cover a wider scope of assessment including the environmental externalities, social costs and whole life cycle of the product or service. Often this will lead to 'win-win' situations whereby a greener product, work or service is also cost-effective [56].

Industrial Symbiosis Indicators

Industrial symbiosis aims to join separated companies in a collective approach in order to achieve the physical exchange of materials, water, energy, logistics and by-products, in order to achieve competitive advantages. In this line, industrial ecology is the study of material and energy flows through industrial systems, with an emphasis on natural capital restoration. It also focuses on social wellbeing. Focusing on connections between operators within the 'industrial ecosystem', this approach aims at creating closed-loop processes in which waste serves as an input, thus eliminating the notion of an undesirable by-product. Local or wider co-operation in industrial symbiosis can reduce the need for virgin raw material and waste disposal, thereby closing the material loop. It can also reduce emissions and energy use and create new revenue streams [57]. Some other key benefits of industrial symbiosis are indicated in Figure 11.:

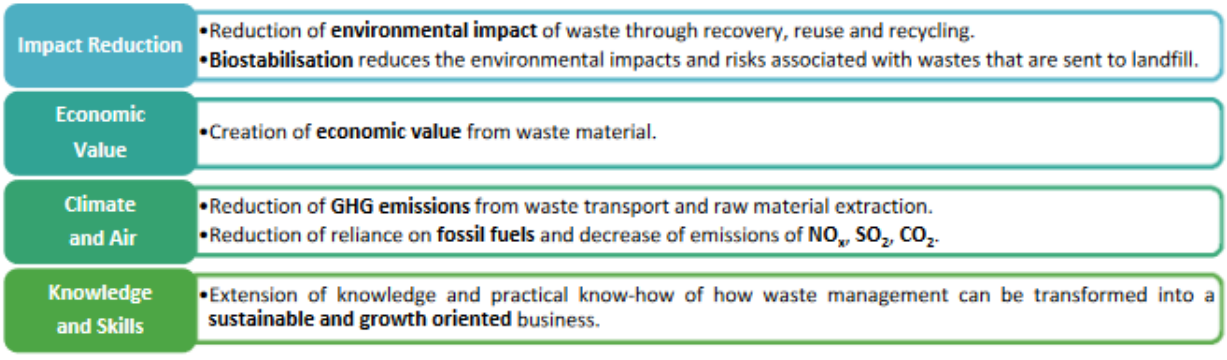

Figure 11. Key benefits of the implementing strategies of industrial symbiosis [58]

The main barriers regarding the implementation of industrial symbiosis include managing close cooperation between industries, governing bodies, stakeholders and also achieving public acceptance [58]. A proper waste management strategy may take time and persistence to develop, and there is a need for waste sorting efficiency at household and consumer level to ensure cost efficiency. Obtaining data on the sources and processing of industrial wastes is also challenging. Guidance, support and regulatory compliance and enforcement can help to overcome these limitations.

A list of these indicators was presented in Table 3 [59], as a result of a systematic literature review to identify the performance indicators for the measurement of industrial symbiosis in Eco-Industrial Parks.

Table 3. Industrial symbiosis indicators [59].

Reference	Indicator(s)
Hardy and Graedel (2002)	a. Connectance b. Symbiotic Utilization
Dai (2010) [a]	a. Eco-Connectance b. By-Product And Waste Recycling Rate
Zhou et al. (2012)	a. Industrial Symbiosis Index b. Link Density
Gao et al. (2013) [a]	a. Ecological Correlation Degree Among Enterprises b. Rate Of By-Products Recycling In EIPs
Park and Behera (2014)	Eco-Efficiency
Wen and Meng (2015)	Resource Productivity Index
Trokanas et al. (2015)	Environmental Impact
Felicio et al. (2016)	Industrial Symbiosis Indicator

Source: adapted from Mantese and Amaral (2016).
[a] Identical indicators with different names.

A selection of some of the previous indicators is described with more detail in this section:

- **Eco-Connectance Indicator**: The Eco-Connectance indicator (Ce) establishes the degree of connectivity between the companies that constitute an industrial park and it depends on the observable (as opposed to potential) by-products and waste flows, and the number of factories or companies in an industrial park.

- **By-product and Waste Recycling Rate**: This indicator defines the degree to which the by-products and wastes of a company are used by other companies in the industrial park

- **Industrial Symbiosis Indicator (ISI):** For the calculation of the ISI indicator [60], it is necessary to evaluate the by-products according to their potential environmental impact. The higher the internal flow of the inbound by-product and the lower the external flow of by-product, the higher is the ISI value (i.e., most of the by-products generated are reused within the park itself and little by-product leaves the park). Conversely, if the external flow of by-product is high, the level of symbiosis will be lower.

- **Symbiotic Utilization:** According to Hardy and Graedel (2002) [61], the Potential Hazard (PH)of each by-product reused as input, must be considered to calculate this indicator. The Potential Hazard will be directly proportional to the by-product classification criteria according to the Industrial Symbiosis Indicator [60].

- **Industrial Eco-Efficiency:** This indicator proposed by Park and Behera (2014) [62] uses the consumed energy, the amount of consumed materials and the emitted CO_2 as inputs for the indicator calculation, The unit of measurement is tons of oil equivalent (toe).

- **Resource Productivity Index:** This indicator uses the substance flow analysis so that by-products can be considered equated. In the model presented in [59], the amounts of the standard transformation process are the amounts of a substance (resources, water and energy).

- **Industrial Environmental Impact**: According to Trokanas et al. (2015) [63], this indicator is composed of five sub indicators which will be finally weighted, namely Embodied Carbon Cost (ECC), Virgin Materials Financial Saving (VMFS), Landfill Diversion Financial Saving (LDFS), Transportation Financial Impact (TFI) and Energy Consumption Financial Impact (ECFI).

- **Resilience Indicator**: The resilience indicator is composed by two factors: the connectivity of a park (NCI) and its capacity to endure a disruptive event by replacing flows of a participant in a specific exchange network [64].

Sustainability Indicators

Sustainable Development Goals and Indicators

In 2016, the United Nations announced the creation of the 17 Sustainable Development Goals (SDGs), listed in Figure 12., which can be found in the 2030 Agenda for Sustainable Development [51] and also updated on the website https://ec.europa.eu/eurostat/web/sdi/main-tables. The SDGs are integrated and indivisible, global in nature and universally applicable, considering different national realities, capacities and levels of development and respecting national policies and priorities. In order to assess the targets, a list including 230 indicators was agreed and they will be considered when deciding the most relevant indicators regarding this project.

Figure 12. Sustainable Development Goals [51]

Sustainable Development Strategy is one of the important drivers for the utilization of sustainability indicators. In this line, European Commission must develop indicators to monitor outcomes of the

sustainability efforts. New Sustainable Development Indicators (SDIs) have been developed and existing indicators are updated whenever necessary in order to supply proper information on key environmental, economic and social issues during the policy-making process [65]. The SDI set of is organized by thematic framework, including: socioeconomic development, sustainable consumption and production, social inclusion, demographic changes, public health, climate change and energy, sustainable transport, natural resources, global partnership, good governance [55].

Table 4. Methods of SDIs regarding scale, normalization, weighting and aggregation, extracted from reference [66]

Index	Scale	Normalization	Weighting	Aggregation
Living Planet Index	RNC	$\left(\frac{x_{i,t}}{x_{i,t-1}}\right)$	equal	$\sqrt[N]{\prod_{i=1}^{N}\frac{x_{i,t}}{x_{i,t-1}}}$
Ecological Footprint	RNC	transformation in square km	equal	$\sum_{i=1}^{N} x_i$
City Development Index	RNC	$\frac{x_i - \underline{x}}{\overline{x} - \underline{x}}$	2 steps PCA/experts	$\frac{1}{N}\sum_{i=1}^{N} w_i x_i$
Human Development Index	RNC	$\frac{x_i - \underline{x}}{\overline{x} - \underline{x}}$	equal	$\frac{1}{N}\sum_{i=1}^{N} x_i$
Environmental Sustainability Index 2005	RNC	standard deviation	equal / experts	$\frac{1}{N}\sum_{i=1}^{N} x_i$
Environmental Performance Index	RNC	best = 100 worst = 0	PCA and experts	$\sum_{i=1}^{N} w_i x_i$
Environmental Vulnerability Index	RNC / INC	aim = 1 worst = 7	equal	$\frac{1}{N}\sum_{i=1}^{N} x_i$
Index of Sustainable Economic Welfare	RNC	monetarized	equal	$\sum_{i=1}^{N} x_i$
Well Being Index	RNC	best = 100 worst = 0	subjective (not derived)	$\frac{1}{N}\sum_{i=1}^{N} (w_i) x_i$
Genuine Savings Index	RNC	monetarized	equal	$\sum_{i=1}^{N} x_i$
Environmentally Adjusted Domestic Product (EDP)	RNC	monetarized	equal	$\sum_{i=1}^{N} x_i$

With variables represented by x_i, weights by w_i, and countries by i and years by t.

European Environment Agency Core Indicator Set

The European Environment Agency (EEA) has developed the core indicator set (CSI). It seeks to implement a manageable and stable ground for indicator-based assessments to monitor the progress in priority environmental policy areas [59], [67]. Today, the EEA maintains an extensive set of 137 indicators, grouped in 13 environmental themes, depicted in Figure 13. Therefore, a revision of the CSI aimed to establish an

indicator set with a more balanced structure and an improved alignment with current policy priorities and the EEA's Multiannual Work Programme 2014–2018, which aims to support environment and climate policy implementation priorities in Europe. This CSI can be found in Technical report No 8/2014 - Digest of EEA indicators (2014), developed by EEA [49].

Further information available from: www.eea.europa.eu/publications/digest-of-eea-indicators-2014

Themes	Number of indicators
Air pollution	11
Biodiversity	27
Climate change	46
Energy	11
Environmental scenarios	2
Fisheries	3
Green economy	1
Household consumption	1
Land	1
Soil	1
Transport	20
Waste	2
Water	11
Total	137

Figure 13. EEA core indicator set (updated version 2014)

Finally, a list of Indicators can be found in the third edition of the annual "European Environment Agency (EEA) Environmental indicator report— in support to the monitoring of the European Union Seventh Environment Action Programme", which updates last year's results and information data (mainly from 2016 and 2017). The Seventh Environment Action Programme 2014-2020 provides an overarching strategic framework for EU environment policy planning and implementation. This report examines — with the help of 29 indicators — if the EU is on the right path to achieve the 7th EAP's three thematic priority objectives by 2020. It highlights three thematic priority objectives:

1. 'Protect, conserve and enhance the Union's natural capital';

2. 'Turn the Union into a resource-efficient, green, and competitive low-carbon economy';

3. 'Safeguard the Union's citizens from environment-related pressures and risks to health and well-being'.

Table 5 summarises the indicator results across the three priority objectives in a scoreboard. For each indicator, more detailed assessments are available online (www.eea.europa.eu/airs/2018) [68].

Table 5. List of indicators and corresponding Annual Indicator Report Series (AIRS) 2018 briefings by 7th EAP thematic priority objective

Indicators	Briefings
Priority objective 1: to protect, conserve and enhance the Union's natural capital	
Exposure of terrestrial ecosystems to eutrophication due to air pollution	Eutrophication of terrestrial ecosystems due to air pollution
Gross nutrient balance in agricultural land: nitrogen	Agricultural land: nitrogen balance
Land take	Urban land take
Forest: growing stock, increment and fellings	Forest utilisation
Status of marine fish and shellfish in European seas	Marine fish stocks
Abundance and distribution of selected species (common birds and grassland butterflies)	Common birds and butterflies
Species of European interest	EU protected species
Habitats of European interest	EU protected habitats
Status of surface waters	Surface waters
Priority objective 2: to turn the Union into a resource-efficient, green and competitive low-carbon economy	
Resource productivity	Resource efficiency
Waste generation in Europe (excluding major mineral wastes) absolute and per capita levels	Waste generation
Recycling of municipal waste	Recycling of municipal waste
Use of freshwater resources	Freshwater use
Total greenhouse gas emission trends and projections	Greenhouse gas emissions
Share of renewable energy in gross final energy consumption	Renewable energy sources
Progress on energy efficiency in Europe	Energy efficiency
Energy consumption by households	Household energy consumption
Greenhouse gas emissions from transport	Transport greenhouse gas emissions
Animal product consumption (animal protein)	Food consumption — animal based protein
Share of environmental and labour taxes in total tax revenues	Environmental and labour taxation
Employment and value added in the environmental goods and services sector	Environmental goods and services sector: employment and value added
Environmental protection expenditure in Europe	Environmental protection expenditure
Priority objective 3: to safeguard the Union's citizens from environment-related pressures and risks to health and well-being	
Exceedance of air quality standards in urban areas (nitrogen dioxide: NO_2; dust particles: PM_{10}; ozone: O_3; fine particulate matter: $PM_{2.5}$)	Outdoor air quality in urban areas
Emissions of the main air pollutants in Europe (sulphur oxides: SO_2; nitrogen oxides: NO_x; ammonia: NH_3; non-methane volatile organic compounds: NMVOCs; fine particulate matter: $PM_{2.5}$)	Air pollutant emissions
Bathing water quality	Quality of bathing waters
Number of countries that have adopted a climate change adaptation strategy and/or plan	Number of countries that have adopted a climate change adaptation strategy/plan
Population exposure to environmental noise	Environmental noise
Consumption of chemicals by hazard class	Consumption of hazardous chemicals
Total sales of pesticides	Pesticide sales

- Study of the European Academies' Science Advisory Council (EASAC)

EASAC is conducting also a study against the backdrop of the Commission's commitment to develop a set of reliable indicators for monitoring progress towards a circular economy. After a review of the existing indicators at macro and private level, some relevant indicators are proposed to create the Circular Economy Indicator System (CEIS). It can be found in more detail in [69].

Table 6. Classification of current indicators potentially relevant to the Circular Economy [69]

Indicator type	Examples	Availability of data	Relevance to the CE
Sustainable development	Social economic development, sustainable consumption and production, social inclusion, demographic changes, public health, climate change and energy, sustainable transport, natural resources, global partnership, good governance (Table A2)	Voluntary based reporting via EU Directorate-General for Energy (focused), European Sustainable Development Network (ESDN); corporate sustainability indicators (e.g. carbon disclosure)	Natural resources, sustainable consumption and production
Environmental	Agriculture, air pollution, biodiversity, climate change, energy, fisheries, land and soils, transport, waste, water	Regulatory based reporting via EEA cores indicators and country-specific statistics	Waste generated, packaging waste generation and recycling
Material flow	Domestic extraction, direct material consumption, domestic material input, physical trade balance, net additions to stock, domestic processed output, total material requirement, total domestic output	Eurostat, SERI	All
Societal behaviour	Sharing, municipal waste recycle, waste generated per capita (total and segregated), environmental/resource taxation	National and voluntary organisation statistics	All
Organisational behaviour	Material flow accounting in organisations, remanufacturing, use of recycled raw materials, eco-innovation, per capita statistics (e.g. reduction in waste generation per capita)	Private sector voluntary reporting via EU Forum for Manufacturing; ZVEI (German Electrical Industrial Association); VDMA (German Engineering Federation); etc.	All
Economy performance	Resource productivity, recycling industry, green jobs, waste generation/GDP, 'transformation of the economy'	Eurostat EU Resource Efficiency Scoreboard	All

In addition, this council aims to promoting the use of composite indicators, for example, as the following equation. This way the indicator would increase if evolving trends are positive (e.g. high GDP, low waste) and decrease in the opposite case.

$$Example\ Composite\ indicator = \frac{GDP^2 \cdot\ Recycle\ rate}{TPES \cdot Population \cdot CO2\ emissions}$$

Circular Economy Indicators

Despite the existence of all this sustainability indicators, a quantifiable sustainability rating would be required for all the manufactured products regarding the circularity degree. In fact, it should be relevant to measure circularity degree of current systems, processes and products to evaluate the remaining distance to achieve a self-sustaining economy, truly circular.

There is no a single indicator for the Circular Economy measurement. However, most indicators can be grouped into [70]:

- Sustainable resource management: focused on lowering resource demands:
  - Resource Productivity (Purchasing power standard per Kilogram)
  - Municipal waste generation (kg/capita)
  - Municipal waste recycled (kg/capita)
- Societal behavior: reflects citizen awareness and participation in the circular economy:
  - Citizens who have chosen alternatives to buying new products
  - Turnover in repair of Computers and Personal Goods

  - Number of enterprises or employees in repair of computers and personal and household goods
  - Coverage of the Circular Economy topic in Electronic Mass Media (articles published)
- **Business operations:** eco-innovation activities towards adapting business models according to the principles of a circularity across the life cycle of material use.
  - Difficulties Implementing circular economy activities experienced by companies
  - Financing sources for circular economy activities
  - Availability of information to access finance for circular economy related activities
  - Share of enterprises that facilitated recycling of products after use
  - Enterprises that extended product life through more durable products
  - Enterprises that recycle waste, water or materials.

The importance of the circular economy to European industry was recently highlighted in the renewed EU industrial policy strategy [71]. After the adoption of EU Circular Economy Action Plan (COM/2015/0614) [70], the European Commission released a new set of measures in January 2018. The Circular Economy Package mainly includes a "Monitoring Framework on Progress Towards a Circular Economy", [72] "EU Strategy for Plastics in the Circular Economy" [11] and the "Report on Critical Raw Materials and the Circular Economy" [73].

The European Commission states that a single score would not be enough to properly indicate the complexity of circular economy. So, the indicators for monitoring the transition towards circular economy are grouped into four stages and aspects of circular economy (Figure 14). All these indicators are displayed for each country and for the whole EU in [74]. The Communication COM(2018)29 [72] implements this commitment by putting forward a monitoring framework composed of a set of key meaningful indicators which capture the main elements of the circular economy [72]; which are listed in Table 7 although it must be considered some of them are still under development.

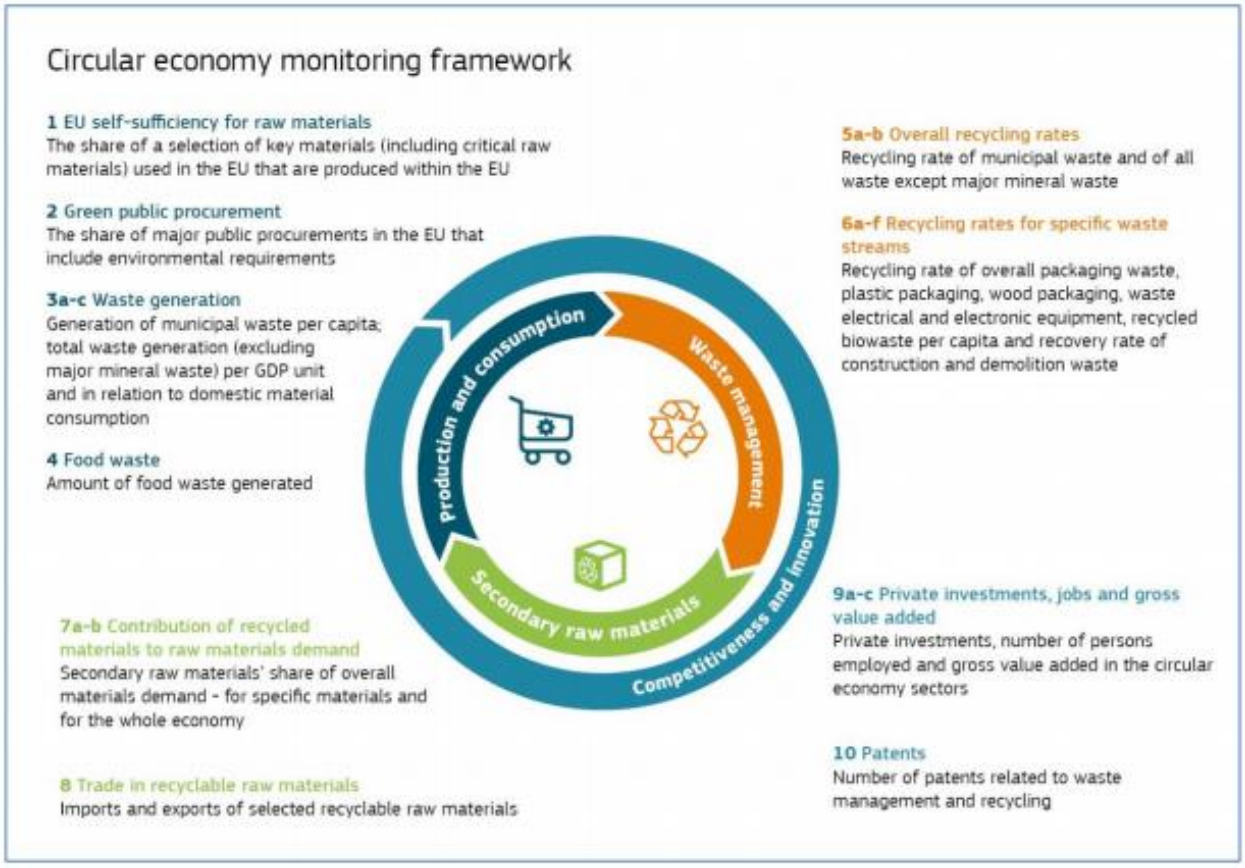

Figure 14. Circular economy monitoring framework [72]

- Production and consumption: EU is found to be less self-sufficient in the area of critical raw materials. Green public procurement can be a driver for circular economy and innovation. The municipal waste generation reduced by around a 10%; while total waste generation decreased by 11% from 2006 and food waste dropped by 7% between 2012 and 2014.
- Waste management: EU recycling rates for municipal waste has increased from 37% to 46% to 2016. While some countries are approaching towards the EU target for recycling there are others which are still behind the target.
- Secondary raw materials: Recycled materials satisfy 10% of the EU's raw material demands. One bottleneck for this rate can be the fact that it is not profitable to recycle some raw materials.
- Competitiveness and innovation: The transition to a circular economy increases investments, value added and jobs, and stimulates innovation.

Table 7. Indicators on the circular economy included in the monitoring framework [72]

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

Additionally, the circular economy related indicators gathered from now on have been chosen to specifically quantify the sustainable developments in industries after a further literature review.

- **Circular Economy performance indicator (CPI):** This indicator represents the ratio of the actual obtained environmental benefit from a system (i.e. of the currently applied waste treatment option) over the ideal environmental benefit, or in other words, the benefit of the waste treatment option to which the stream should be directed according to its composition/quality with a minimal

required effort, assuming option I (closed-loop recycling) is better and option IV (incineration) is less preferable [75].

- **Linear Flow/Circular Flow Index:** Linear flow index (LFI) provides insight on how linear a production model is, which is represented by the proportion of material flowing in a linear manner from virgin materials to unrecoverable waste. This proportion is calculated by dividing the total amount of materials flowing in a linear way by total amount of materials within the entire production system collectively comprised of linear and circular fashions (i.e. total mass flow) [3].

- **Product Utility:** Utility accounts for the length of a product's use phase (lifetime) and intensity of use (function). The length of useful lifetime can be defined as the ratio of lifetime of the product in question to average lifetime of the similar products with same function on the market. The intensity reflects the extent to which a product is used to its full capacity and can be considered as the number of times it serves it function before it reaches the end-of-life stage [3].

- **Material Circularity Indicator (MCI):** This indicator measures how circular is a production system and how long and intensely the product in question is being used. It is comprised of the amount of virgin materials used during production stage, amount of unrecoverable waste generated at the end of product life cycle and utility factor explained in the previous section [3].

- **Material Reutilization Score (MRS):** Addressing the product level assessment with regard to the technical cycle, the MRS is the metric used to quantify the material recyclability potential of a product by the weighted average of the two variables: the intrinsic recyclability (IR) of the product, i.e. the % of the product that can be recycled at least once after its initial use stage and the % of recycled content (RC) [47].

- **Resource Productivity:** European Commission's Roadmap to Resource Efficient Europe (2011) proposes "resource productivity" as a provisional lead indicator with a series of impact-based indicators [76]. Resource productivity is measured by the ratio of GDP to Domestic Material Consumption and is expressed in Euro/tonne. The higher the resource productivity, the better the performance, with growth consuming relatively fewer resources. However, this indicator only captures the material resources aspects and does not involve other resources or the potential shift of burden across countries.

- **Value-based Resource Efficiency:** Maio et al. (2017) [77] criticise the material flow indicators since they do not support decision making. Economic value should be used to measure resource efficiency. Unlike mass representing only the quantity, economic value involves both quantity and quality, i.e., environmental and social value. Monetary value embodies environmental costs and other external costs by means of taxes and permits policy makers to identify and monitor stressed resources. Moreover, social value is also included in economic value through the mechanism of taxes and incentives.

- **Circularity of resources and Longevity:** Figge et.al (2018) claims that circularity is expressed as the number of times a resource is used in a product system [45]. It is composed by three components: 'initial use', 'refurbishment' and 'recycling'. Similarly, Franklin et al. (2016) comments that current indicators based on burden of a product relative to its value are not adequate to evaluate circular economy and suggests a new performance metric called "longevity indicator". Longevity indicates time to measure the retention of a material within a product system, where greater retention means that the use of the resource is maximised. Longevity can be utilized by companies to evaluate their contribution to circular economy or for material selection in design phase to enable continued material and product retention [78].

- **Recycling indicators related to environment benefits:** The objective of the study developed by Huysveld (2019) [43] on the Recyclability Benefit Rate (RBR) and Recycled Content Benefit Rate (RCBR) indicators is to clarify the monitoring of the environmental benefits of material cascading.
  - RBR indicator equals the ratio of the net environmental savings that can be obtained from recycling a product, over the net environmental burdens related to virgin material production and disposal. This indicator is developed from the product's end-of-life or waste perspective.
  - RCBR indicator equals the ratio of the net environmental savings that can be obtained from introducing recycled material in a product, over the net environmental burdens related to virgin material production, manufacturing, use and disposal. This indicator is developed from the new product designer's perspective.

4 MARINE LITTER IMPACTS

4.1 BACKGROUND AND CURRENT SITUATION

Every year, the sum of humanity's knowledge increases exponentially. And as we learn more, we also learn there is much we still don't know. Plastic litter in our oceans is one area where we need to learn more, and we need to learn it quickly to deal with this important problem [7].

"Marine litter (also called marine debris) is waste created by humans that has been discharged into coastal or marine environments, resulting from activities on land or at sea" [79]. It is composed of any manufactured or processed object (including glass, metals, paper, textiles, wood, rubber, and plastics) that are discarded, disposed, abandoned in the environment, or brought indirectly to the sea by rivers, sewage, storm water, waves, or winds.

Some of these materials may be easily biodegradable (paper, wood, or natural fibres), whereas others are highly persistent in the marine environment. There are some long lived non-plastic materials in the marine debris (like wood, ceramic and metallic artefacts), but most of them are plastics materials. Plastics are the most abundant materials in marine litter because of their resistance (to biodegradation) and their light weight, that makes them easily transportable by wind and water [6].

The abundant presence of plastics as litter in the environment reflects the high dependence we have on these materials in our daily life. Considering the vital importance of plastics for modern life, it is not expected that plastics production and use was restricted anytime soon. If the current trend of a 5% production increase per year continues, another 33 billion tonnes of plastic will have accumulated around the planet by 2050 [80]. Currently, many researchers are looking for solutions able to reduce the huge impact of plastic waste over the oceans, and this problem could get worse in future years if mitigations solutions are not urgently implemented.

Sources of marine plastic debris

Today´s deterioration of the global environment is closely linked to unsustainable patterns of consumption and production. The exponential increase in production and consumption in all sector over the last years, has generated a vast amount of waste, much of it contributing to marine litter. This includes waste streams such as wood, textiles, metal, glass, ceramics, rubber and above all, plastic [7]. Focusing on plastics, due to the high durability of the material and their low percentages of recycling or reuse, accumulation of plastic waste throughout the planet is increasing permanently. [81]. Between 60 % and 90 % (sometimes as much as 100 %) of the litter that accumulates on shorelines, the sea surface and the sea floor is made up of one or a combination of different plastic polymers. The most common items, constituting over 80 % of the litter stranded on beaches are cigarette butts, bags, remains of fishing gear, and food and beverage containers. Likewise, 90 % of the litter collected from sea floor trawls is made up of plastic [7].

Because of human activities are varied and widespread, sources and pathways of marine litter are diverse and exact quantities and routes are not fully known. Reliable quantitative estimations of input loads, sources and pathways represent a significant knowledge gap. However, there is a lot of research that aims to determine them [80]. According to recent investigations, most of the plastic in our oceans (around 80 to 90 %) comes from land-based sources (including via rivers) [82], and only a small portion comes from ocean-

based sources (such as fisheries, aquaculture and commercial cruise or private ships) [83]. A study by Jambeck et al. [84] estimated that between 4.8 and 12.7 million tons of land-based plastics leak to the ocean every year. According to Lebreton et al. study [85], between 1.15 and 2.41 million tons of this land-based plastic waste, ends up in the ocean through the rivers. The top 20 of polluting rivers were mostly located in Asia and accounted for 67 % of the total. Furthermore, Jambeck et al. [84] observed that developing economies are the most polluting. The study reveals that, 83% of land-based plastic waste that ends up in the ocean originates from 20 countries (China, Indonesia, the Philippines, Vietnam, Sri Lanka, Thailand, Egypt, Malaysia, Nigeria, Bangladesh, South Africa, India, Algeria, Turkey, Pakistan, Brazil, Burma, Morocco, North Korea and the United States) (Table 8).

Table 8. Waste estimated for 2010 for the top 20 countries ranked by mass of mismanaged plastic waste (in units of millions of metric tons per year)

Rank	Country	Econ. classif.	Coastal pop. [millions]	Waste gen. rate [kg/ppd]	% plastic waste	% mismanaged waste	Mismanaged plastic waste [MMT/year]	% of total mismanaged plastic waste	Plastic marine debris [MMT/year]
1	China	UMI	262.9	1.10	11	76	8.82	27.7	1.32–3.53
2	Indonesia	LMI	187.2	0.52	11	83	3.22	10.1	0.48–1.29
3	Philippines	LMI	83.4	0.5	15	83	1.88	5.9	0.28–0.75
4	Vietnam	LMI	55.9	0.79	13	88	1.83	5.8	0.28–0.73
5	Sri Lanka	LMI	14.6	5.1	7	84	1.59	5.0	0.24–0.64
6	Thailand	UMI	26.0	1.2	12	75	1.03	3.2	0.15–0.41
7	Egypt	LMI	21.8	1.37	13	69	0.97	3.0	0.15–0.39
8	Malaysia	UMI	22.9	1.52	13	57	0.94	2.9	0.14–0.37
9	Nigeria	LMI	27.5	0.79	13	83	0.85	2.7	0.13–0.34
10	Bangladesh	LI	70.9	0.43	8	89	0.79	2.5	0.12–0.31
11	South Africa	UMI	12.9	2.0	12	56	0.63	2.0	0.09–0.25
12	India	LMI	187.5	0.34	3	87	0.60	1.9	0.09–0.24
13	Algeria	UMI	16.6	1.2	12	60	0.52	1.6	0.08–0.21
14	Turkey	UMI	34.0	1.77	12	18	0.49	1.5	0.07–0.19
15	Pakistan	LMI	14.6	0.79	13	88	0.48	1.5	0.07–0.19
16	Brazil	UMI	74.7	1.03	16	11	0.47	1.5	0.07–0.19
17	Burma	LI	19.0	0.44	17	89	0.46	1.4	0.07–0.18
18*	Morocco	LMI	17.3	1.46	5	68	0.31	1.0	0.05–0.12
19	North Korea	LI	17.3	0.6	9	90	0.30	1.0	0.05–0.12
20	United States	HIC	112.9	2.58	13	2	0.28	0.9	0.04–0.11

*If considered collectively, coastal European Union countries (23 total) would rank eighteenth on the list

One of the most important factors related with annual waste generation and marine pollution is population size, and more specifically coastal population. Most of the top waste-producing countries have large coastal population, so these countries are potential emitters of high amounts of marine litter. However, another factor that is also important when assessing the largest contributors of waste that is available to enter the environment, is the percentage of mismanaged waste (Figure 15). Sixteen of the top 20 producers are middle-income countries with a growing economy, but with a waste management infrastructure at a low development level (the average mismanaged waste rate is 68 %). Only two of the top 20 polluting countries have mismanaged waste percentages lower than 15 % (United States and Brazil). Here, even though some countries have relatively low mismanaged rate, its contribution to the marine litter is very significant because of large coastal populations and, especially in the United States, because of the high per capita waste generation [84].

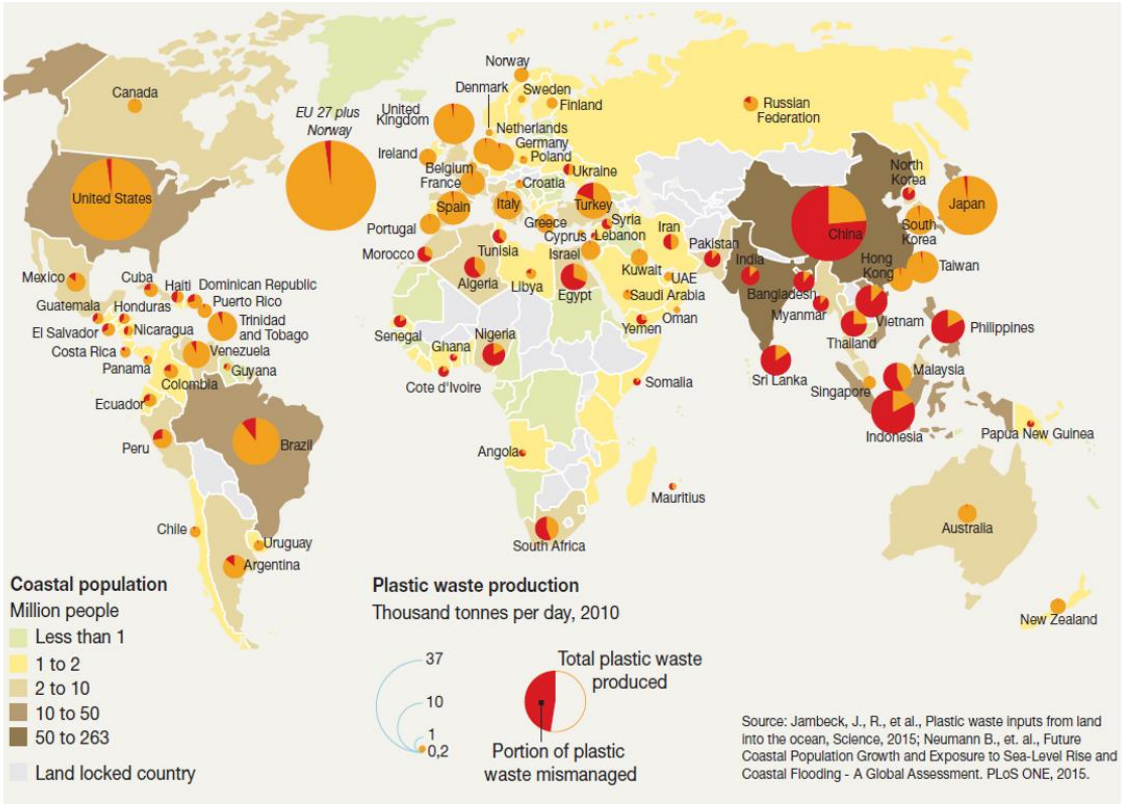

Figure 15. Plastic waste produced and mismanaged

As a result of the large amounts of plastic that ends up in the ocean around the world, it is estimated that the ocean may already contain over 150 million tonnes of plastic, of which around 250,000 tonnes may be floating at the ocean's surface [83]. Areas with high densities of marine debris (mainly plastics) have been found in different places of the oceans, which are known as "garbage patches". These natural gathering points appear where rotating currents, winds, and other ocean features converge to accumulate marine debris, as well as plankton, seaweed, and other sea life. However, the debris is not settled in a layer at the surface of the water, but can be found from the surface, throughout the water column, and all the way to the bottom of the ocean. Marine litter is constantly mixing and moving, so that, high densities of plastics and other debris can been found in very remote and uninhabited places [80] [86].

Plastic size distribution / Microplastics

Most of the marine litter consists of plastics, which are found in all sizes. Plastics are generally divided into two groups: macroplastics and microplastics (including nanoplastics). Macroplastic are formed by all objects bigger than 5mm. There are large objects (tens of metres in length) like fishing nets or cargo containers; moderate sized objects (less than one metre long) such as plastic bags and other packaging, buoys, balloons; and small macroplastics (<2.5 cm) originated from direct and indirect sources such as lost bottle caps or plastic fragments. Microplastics includes all the plastic particles less than 5 mm in diameter. The smallest microplastics (<1µm) are known as nanoplastics. There are two types of microplastics; primary microplastics that have been made intentionally (such as pellets or microbeads, which are present in cosmetic products and synthetic cloth fibres) and secondary microplastics that are fragmented parts of larger plastics [7], [80].

The concern about microplastic pollution is due to its ubiquitous presence in the marine environment. Yet it is difficult to assess its quantity because of the small size of the particles and the fact that little is known about the chemical reactions and the extent of its incorporation into the trophic chain. Investigations are also being conducted into the implications of organisms' exposure to and intake of plastic nanoparticles, particles smaller than 1 µm. With such limited knowledge of the ultimate ecological effects of microplastics and nanoplastics, there are concerns over their potential impacts at the level of ecosystems [7].

4.2 MARINE LITTER ENVIRONMENTAL IMPLICATIONS

The versatility of plastics and its resistance make this material ideal for the manufacture of many types of objects and materials that we use in our daily live. Consequently, we produce, use and throw large amounts of plastic that could represent a hazard to our health or to the environment. Nowadays, plastics are one of the most widespread sources of marine pollution. Their presence in the aquatic habitats, only increases the number of ecosystems and organisms vulnerable to their exposure. In addition to environmental effects, marine litter can also cause significant economic and social damage.

Most of plastics are extremely durable because they are not biodegradables. Polymers used to manufacture plastics will persist in environment for decades and probably for centuries, if not millennia. Nevertheless, it is impossible to know with certainty how long they last in the marine environment because plastics have only been mass-produced for around 60 years. There is another type of plastics, so-called biodegradable plastics, which can decompose through the mediation of certain micro-organisms. But even these plastics may persist for long periods under marine conditions because their degradation depends on physical factors, such as exposure to light, oxygen and temperature [7].

Full degradation of a plastic consists of complete decomposition into water, carbon dioxide, methane and other non-synthetic molecules. For most plastic items, even if they break down into smaller and smaller plastic debris under the influence of weathering, the polymer itself may not necessarily fully degrade into natural chemical elements under marine conditions [7].

Plastics in the marine environment may also present an additional chemical hazard, especially those containing chemical additives or contaminants, because some of them are known to be toxic to marine organisms and to humans. These substances may be introduced directly into marine species during the feeding process or may be filtered to the marine environment when the plastic deteriorates. The chemicals found in plastic marine litter can be classified in the following four categories of origin [83]:

- Chemicals intentionally added during the production process (additives such as flame retardants, plasticizers, antioxidants, UV stabilisers, and pigments).
- Unintentional chemicals coming from the production processes, including monomers (e.g. vinyl chloride, BPA, etc.)- which may also originate from UV radiation onto the plastic waste - and catalysts, normally present in traces (ppm).
- Chemicals coming from the recycling of plastic waste.
- Hydrophobic chemicals or heavy metals adsorbed from environmental pollution onto the surface of the plastics.

Due to the concern for the increasing presence of plastics in the environment, more and more researchers are studying not only the quantity but also the risks and ecological, social and economic impacts of plastics.

Impacts on marine biodiversity

Marine environment is the principal ecosystem affected by plastics due to the large amount of macro and microplastics around the ocean, from the poles to the equator and from the sea surface to the depths of the ocean. One of the most obvious and visually recognized impacts are the entanglements of marine species in different items of marine litter (such as fishing nets, plastic bags or plastics six pack rings). This risk, that affects numerous species, can cause physical injuries that diminish the swimming or mobile capacity of the animals and, in the worst cases, can cause a quick or a slow death through drowning, starvation, strangulation or cuts infection [7], [81]. Much of the damage to organisms is caused by fishing equipment that are abandoned or lost at sea and is known as “ghost fishing” [81]. Gall and Thompson [87], reported that more than 30,800 individuals from 243 species (of which 17 % are in danger of extinction) were victims of entanglements. This problem affects a variety of marine mammals, reptiles, birds and fish, especially higher taxa organisms like whales, turtles, seals, dolphins, sharks and large fishes.

Another important risk is the ingestion of plastics by different marine organisms. Ingestion of plastic is less visible than entanglement, but affects a large variety of marine mammals, reptiles, seabirds and fish [82]. According to Gall and Thompson [87], plastic ingestion has been reported in more than 13,110 individuals from 208 species. However, evidence of ingestion often comes from the dissection of death individuals (such as beached carcasses), which represents an unknown proportion of the total number of individuals affected.

Plastics may be ingested intentionally or accidentally. Sometimes, species confuse marine litter, and especially plastic, with food, ingesting some items intentionally. On the other hand, some species obtain their nutrition by filtering large volumes of water, ingesting accidentally plastics instead of food [88]. The ingestion of plastic, intentionally or accidentally, can cause direct death through the simple physical obstruction of the stomachs, or affect the organisms through various stomach dysfunctions. Plastics can produce partial blockage or damage to the digestive tract and reduction in appetite due to feelings of satiation, all of which can result in poor nutrition and a consequent decline in health or even death [81].

Apart from the physical risk from plastic, there is also concern that marine organisms are at risk from the ingestion of hazardous chemicals that are in the plastic or adsorbed on its surface. Also, the degradation of plastics into the stomachs of organisms may release toxic substances such as persistent organics pollutants or other dangerous additives.

Furthermore, special mention should be made about microplastics. Small microplastics an fibers can have similar size characteristics to sediment and suspended particulate matter and can be ingested by filter feeding or sediment ingesting organisms such as marine worms, amphipods, sea cucumbers mussels or barnacles. Even very small organisms at the bottom of the food chain, like filter feeding zooplankton, have been observed to take up microplastics. Although research is still insufficient, the ingestion of microplastics by organisms in the lower levels of the trophic chain can be an simple way to incorporate microplastics by organisms in higher levels of the trophic chain [7], [81].

With reference to the transfer of chemicals from plastics, there is some scientific evidence suggesting endocrine disruptor activity relating to the intake of chemicals associated with microplastics via the filter feeding mechanisms of animals like mussels or baleen whales, or via the magnifying effect of the food chain in top predators such as the swordfish. Some of the substances which are part of the plastics, are recognized as endocrine disrupting chemicals (EDCs). Widely used plasticizers such as dibutyl phthalate, dimethyl phthalate, butyl benzyl phthalate, or plastic monomers such as Bisphenol A (BPA), can affect both development and reproduction in marine species. Other EDCs, such as tin-containing plastic stabilisers, can produce immunological disorders in fishes. However, even though the huge amount of harmful effects that have bene demonstrated, it should be remarked that there are still basic knowledge gaps, including the long-term exposures to environmentally relevant concentrations and their ecotoxicity when part of complex mixtures [83].

Impacts on human health

Assessing the potential effects of microplastic in humans is a complex process that is still under study. However, it is evident that humans are exposed to micro and nanoplastics through the consumption of seafood. A wide variety of commercial species appear to be contaminated with microplastics such as shellfish, shrimp, small fish species, sea urchins, and sea cucumbers. However, consumption of filter feeding invertebrates, such as mussels or oysters, appears the most likely route of human exposure to microplastics because people eat the whole organism including the gut [7], [82]. An study of Cauwenberghe and Janssen [89] estimated that high consumers of mussels in Belgium could ingest more than 11,000 pieces of microplastic in a year (around 90 particles per meal). Microplastic particles ingested could represent a human health risk if they move from the digestive system and come into contact with organs and tissues [7].

In addition, another potential human health hazard is the chemical toxicity of some components of plastics such as plasticizers, flame retardant, antioxidants and other additives. There is research that indicates that some of these chemicals could affect human endocrine system, especially during embryo and infancy stages, or induce hepatic stress or other related health affections [83]. The most worrying chemicals are phthalates and bisphenol A (BPA), that may be carcinogenic and have prejudicial effects in reproductive function. Furthermore, polymers could be dangerous if decompose in their monomers. Polymer families such as polyurethanes, polyacrylonitriles, PVC, epoxy resins, and styrenic copolymers (ABS, SAN and HIPS), are ranked as the most hazardous ones, because they are made of monomers that are classified as mutagenic and/or carcinogenic (category 1A or 1B). Nevertheless, further scientific research is needed with urgency to evaluate the potential impacts of plastics in human health, especially on developing stages, by the direct or indirect ingestion of marine micro and nanoplastics [7].

Impacts on economic activities

Marine plastic debris and microplastics affect negatively to ecosystems and can cause different direct and indirect socio-economic impacts. Knowing all the impacts as well as the full economic and social costs is a difficult task. However, knowledge is fundamental to the development of effective and efficient methods for reducing potential impacts. The main economic activities directly affected by marine plastic debris and microplastics include commercial shipping, fishing and aquaculture, tourism and recreation [7], [82].

- In the shipping sector, marine litter can produce vessels damage and can pollute ship propulsion equipment or cooling systems causing breakdowns and delays. There are direct costs associated with repairs, rescue efforts, and loss of life or injury, but also indirect costs related to loss of productivity and disrupted supply chains, leading to revenue losses [7].
- In the fishing sector, there are also direct and indirect impacts related to presence of marine litter in ocean. Direct costs are linked to damage of fishing vessels and equipment and contamination of the catch with plastic debris. Indirect costs include loss of target species due to ghost fishing by discarded gear and mortality related to ingestion of marine litter.
- In the tourism sector, socioeconomic costs are related to the pollution of beaches and coasts. Firstly, the presence of marine litter has an attractiveness visual impact which can reduce the number of tourists. Also, the presence of marine litter can affect recreational activities such as diving, snorkelling, or recreational fishing. The reduction of visitor numbers affects the tourism sector and leads to a loss of revenue and jobs in the local and regional economy. Secondly, coastline clean-up can imply important costs to local authorities in many cases [7], [82].
- Alongside the economic costs, there are also social costs associated with marine litter such as: reduced opportunities for recreational activities; loss of physical and psychological benefits of coastal environments (like tension and stress reduction) and health risks to coastal visitors (like cuts from sharp items) [7].

Although it is difficult to determine all the impacts associated with marine plastic debris and microplastics, it is quite clear that the economic impact together with associated social and ecological dimensions is considerable [82].

4.3 EVALUATION METHODS FOR MEASURING PLASTIC EFFECTS IN MARINE SYSTEMS

Despite the growing problematic currently existing with the plastic accumulation, the impacts of marine plastic (and most especially microplastic) is a relatively recent field that is still under investigation. Given the novelty of marine plastic research, and the variety of available approaches, there is no one recognised standardized methodology for quantification, characterization and toxicity analysis of the plastic debris. In the last few years, many studies have been done in this area in which researchers use a variety of different techniques and methodologies. Therefore, it is necessary to work on standardisation, or at least harmonisation, of methods used for plastic analysis to allow a precise comparison of data and also, to establish common indicators for assessment of microplastics in the marine environment.

Nevertheless, overviewing the existing literature, some methodologies have been found to assess the impacts of marine plastic. To evaluate the global impact of ingestion and entanglement of different species in plastic, the most appropriate method is to perform a review of the different documented cases regarding the studies carried out over different species in different geographical areas. Under this approach, some researches such as Gall and Thompson [87], and Kuhn et al. [90] have investigated about the number of species strongly affected as well as the different impacts that plastics cause in the individuals. Besides, in that report [91], the authors perform a comparison with the number of affected species identify in other studies (Table 9).

Table 9. Number of species with records of entanglement and ingestion documented in several reports [91].

		Number of species with entanglement records			Number of species with ingestion records		
Species Group	**Total number of known species**	**SCBD (2012) (%)**	**Gall & Thompson, 2015 (%)**	**This report (%)**	**SCBD (2012) (%)**	**Gall & Thompson, 2015 (%)**	**This report (%)**
Marine Mammals	115	52 (45%)	52 (45%)	53 (46%)	30 (26%)	30 (26%)	46 (40%)
Fish	16754	66 (0.39%)	66 (0.39%)	129 (0.77%)*	41 (0.24%)	50 (0.30%)	62 (0.37%)
Seabirds	312	67 (21%)	79 (25%)	80 (26%)	119 (38%)	122 (39%)	131 (44%)
Marine Reptiles	70	7 (10%)	7 (10%)	8 (11.4%)	6 (8.6%)	6 (8.6%)	6 (8.6%)
Brackish Turtles	6	n/a	n/a	1 (16.7%)	n/a	n/a	0

*: remains as 66 species (0.39%) if ghost fishing records are excluded

In the case of microplastics, there is neither a standard methodology to assess their global impacts on marine species and human health. However, there are some investigations that employ well defined methodologies to evaluate the impact of plastic, not in a global level, but in more specific cases. Galgani et al. [79] use a methodology based on the European Marine Strategy Framework Directive (MSFD,2008/56/EC) to monitoring the impact of litter in large vertebrates in the Mediterranean Sea. In this directive, the European Commission identified the following points as focuses for monitoring:

(i) Trends in the amount, source and composition of litter washed ashore and/or deposited on coastlines.
(ii) Trends in the amount and composition of litter in the water column and accumulation on the seafloor.
(iii) Trends in the amount, distribution and composition of micro-particles (mainly micro-plastics).
(iv) Trends in the amount and composition of litter ingested by marine animals.

Another technique found in the literature to monitoring the marine litter impacts on biodiversity is the use of some marine organisms as bioindicator species. One example of application of this method is the study carried out by Fossi et al [92]. They used marine organisms as bioindicator species and apply a new integrated approach to monitoring the plastics impacts on Mediterranean biodiversity. The methodology used is the following:

1. Review of the current knowledge of the impact of litter on Mediterranean marine organisms.
2. Definition of selection criteria for the choice of sentinel (bioindicator) species.
3. Detection of the presence and impact of marine litter in bioindicator species.

The proposals to monitoring the presence and impact of marine litter in bioindicator species (3.) are:

1. Analysis of gastro-intestinal content to evaluate the marine litter ingested by the organisms, with a particular focus on plastics and microplastics. The results of this analysis must focus on assessing the occurrence (%), abundance (n), weight (g), colour, polymer type of the marine litter and microplastics ingested by the different species;

2. Quantitative and qualitative analysis of plastic additives (e.g. phthalates and PBDEs) and PBT compounds used as plastic tracers in the tissues of bioindicators;
3. Analysis of the effects of litter ingestion by biomarker responses at different levels of biological organization (from gene/protein expression variations to histological alterations)

To sum up this literature review, the global concern about the plastic waste leakages into marine environment and the effects that plastic can have over the marine species and also, over the human health, is causing that every day, more and more researchers are working on developing mitigation measures with the aim of stopping the degradation of the marine environment. However, due to the novelty of this concern, there is not a standard methodology to quantify the impacts caused by the marine litter. There is still a long way to go in the development of methods able to reflect the real problems that these plastics can cause not only in the short term but also in future generations.

5 SELECTION OF KPIS FOR POLYNSPIRE PROJECT

A great number of criteria can be tracked but only the most relevant ones will be regarded as KPIs. It is worth noting that the priority of the KPI relevance may vary in function of the subject perspective. For instance, the KPIs associated to sustainability and environment will be strongly supported by the society; while more technical and economical KPI would be crucial for the production process point of view.

Regarding the previous classification, a set of the most suitable KPIs concerning the polynSPIRE project objectives has been selected according to Figure 16. In order to select the most appropriate indicators, the RACER and SMART criteria were taken into account, along the target setting and geographical specifications. There are already examples of RACER and SMART criteria evaluation in the literature for a variety of indicators [39], [93], [94].

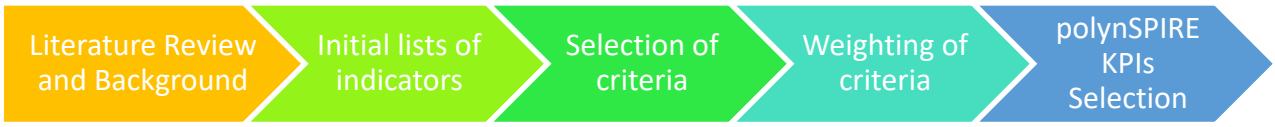

Figure 16. Diagram process of selection of KPIs for polynSPIRE project

In a further step, all the selected KPIs and their characteristics must be validated by the consortium of polynSPIRE to have a common evaluation basis for the project and for future similar replications. Even more, some of these KPIs may be introduced to assess the success of project innovation implementation in the different demo cases.

Hereafter, a Table 10 with a top 10 of the most relevant indicators for the present project will be proposed to the consortium. A brief discussion about the relevance of each indicators follows afterwards.

Table 10. Selection of KPIs for polynSPIRE project

No	Name	Relevance	Associated reports
Ecoefficiency Indicators			
1	Resources and Material consumption (tons)	The circular economy should help to address the supply risks for raw materials, and other material resources, in particular, critical and rare materials.	Raw Materials Initiative; Resource Efficiency Roadmap
2	Energy efficiency (€/ton production)	This indicator quantifies the energy consumption respect to the production, that is, GDP per gross inland energy consumption. Combined pressure and economic indicator	Available from EUROSTAT
3	LCA indicators	Environmental indicators	ISO 14040 family, Carbon Footprint methodologies, EUROSTAT, UNFCCC, EAA
4	LCC indicators	Environmental externalities costs	ISO 14040 family, monetarization references
Industrial symbiosis Indicators			

5	By-product and Waste Recycling Rate (%)	Waste generation, recycling rates, reuse rate, landfill rates, efficiency of valorisation. This reflects the progress in recycling key waste streams. In a circular economy waste generation is minimised.	Waste Framework Directive; directives on specific waste streams; Strategy for Plastics. EUROSTAT reports waste data, but data is inhomogeneous across countries
Sustainability Indicators			
6	Specific recycling rates (%)	This reflects the progress in recycling key waste streams. Increasing recycling is part of the transition to a circular economy. It expresses the adequacy and importance of the waste management.	Waste Framework Directive, EAA EUROSTAT, 2018 Waste management statistics and overall recycling measures; Landfill Directive; directives on specific waste streams
7	Recycling Input Rate (RIR, %)	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
Circular Economy Indicators			
8	MCI (0-1)	It measures how circular a production system and how long and intensely the product in question is being used.	The Circular Economy Package, European Commission's Roadmap to Resource Efficient Europe, Ellen McArthur Foundation, specialized literature
9	Product utility	It is based on a product's lifetime and function adequacy/quality.	The Circular Economy Package, European Commission's Roadmap to Resource Efficient Europe, Ellen McArthur Foundation, specialized literature
10	VRE	It is a ratio of the net value added created per unit of material and energy in monetary units.	The Circular Economy Package, European Commission's Roadmap to Resource Efficient Europe, Ellen McArthur Foundation, specialized literature

1- **RMC** can be calculated for past years and thus allows for analysing past trends. It meets very well the RACER criteria. RMC is easy to compile, transparent, robust, comparable to economic accounts and indicators. RMC focuses on global resource use associated to final consumption in a particular country, city or even company. As such, it enables tracing back any outsourcing of environmental burdens.

2- **Energy efficiency**. Energy consumption has various deep environmental, economic and social implications. Total energy consumption in the EU is dominated by fossil fuels which are the most important source of anthropogenic greenhouse gas emissions. Many other air pollutants are related to fossil fuel combustion. The high dependency on few oil producing countries has many political and economic implications. In addition, the indicator is widely accepted and long used throughout all stakeholder groups with data reported on a regular basis from official sources and allows addressing some of the most important economic, social and environmental issues, giving it highest relevance. The relationship between the turnovers and the production is considered one of the main keypoint of every successful innovative strategy, thus its relevance is very high.

3- **LCA indicators.** An only environmental indicator is not enough to assess its performance, thus, a compilation of several of them is preferred. This concept will cover impact categories such as climate change, ozone depletion, photochemical ozone formation, acidification, eutrophication, human toxicity, land use, resource depletion. Therefore, it is considered as highly relevant. Although it presents some drawbacks, since it is not very easy to have a wide availability of calculated indicators and time series for LCA data are scarce. Besides, there are different methods to calculate them thus the results are not always comparable.
4- **LCC indicator.** It covers added values, avoided burdens and externalized environmental costs which will lead a fairer comparison in favour of circularity. Due to added investment required for installing a circular value chain, this comparison may result in an unfair situation if OPEX and CAPEX are used. NPV is the main economic indicator for which is achieved by discounting all costs and benefits during the scope of the system to the present, and it can be used to demonstrate the economic and environmental advantages of plastic recycling value chain from linear to circular. LCC fulfils this aim and should be preferred over basic indicators.
5- **By-product and Waste Recycling Rate (%).** polynSPIRE project has specific focus on recycling efficiency and not only by itself, but also the connectance between different companies. This is an indicator that reflects the tight connectivity between industries and how some wastes and residues can become input materials is well shared. Therefore, these indicators are considered as highly relevant.
6- **Specific recycling rates**. The recycling rate is calculated as the percentage of overall waste generated that is recycled and composted. This can be done at different levels (company, industrial park, country, etc.). For example, latest available trends show that recycling rates for both municipal waste and packaging waste have increased substantially. It is important to know what the drawback and barriers are to achieve higher rations depending on the material and the sector.
7- **Recycling Input Rate (RIR):** RIR = secondary input / (primary + secondary input). Recycling has a strong link to substances and products, thus measures on recycling have to be set on the meso-or micro level in order to be reasonable and effective. One of the main aims of polynSPIRE project is to increase the secondary raw material consumption (after recycling techniques) and thus to reduce primary raw materials for virgin monomers. This indicator is highly relevant and can easily be adapted to polynSPIRE value chain and demo cases considering the share of recycled plastics.
8- **Material circularity indicator (MCI)** It is comprised of the amount of virgin materials used during production stage, amount of unrecoverable waste generated at the end of product life cycle and utility factor. Material circularity indicator is derived from linear flow index and product utility. MCI is a product-based indicator and can be aggregated for a product range of a company. In polynSPIRE project the use of virgin feedstock will be reduced, indicating an improvement as a result of circularity (MCI increase). Moreover, the project innovations include improvement in recycling processes and rates which will yield in a decrease in the amount of unrecoverable waste generated in recycling process as well as when producing recycled feedstock.
9- **Product Utility**: If the project techniques improve the product lifetime compared to the average products or affecting in the quality and function, product utility can be considered as an indicator that enhances the circularity, then this indicator may be thought as a relevant indicator.
10- **Value based Resource Efficiency (VRE).** The objective is to increase this efficiency either by extending the net value added or reduce the resources needed to create that value added. It includes not only the monetary value gained but also economic value of social and environmental benefits. Therefore,

using such an indicator for assessment will promote circularity by revealing the positive social and environmental impacts.

Other factors to be taken into consideration: **social and public willingness, enterprise commitment and policy support**. The first one reflects citizen awareness and participation in the circular economy. The second one depicts the engagement of eco-innovation activities towards changing and adapting business models according to the principles of a circularity across the life-cycle of material use. And finally, the last one deals with the financing sources or incentives coming from the policy makers to boost and promote circular economy activities. Despite the highly relevancy of these factors, they were not included in the KPIs selection since they are more difficult to be quantified, although it can be done in a qualitative way. Moreover, these are aspects that do not depend directly on the innovation of the polynSPIRE during execution. However, it is expected that after finalizing, it may serve as an example and guidelines to circular economy action, thus leading in a strong impact on public, enterprise and policy acceptance.

Finally, regarding the indicators that can be used to measure the impacts cause by the marine litter, there is not a clear consensus between the researchers about the indicators that must be used to quantify the direct and indirect burdens associated with the plastic waste leakage. However, the continuous use of the same indicators over time is necessary to ensure the comparability of results and assess improvements of the implemented innovations. It is important to keep stability in the formulation of indicators so that they can be compared over time, since indicators reported at different times become a powerful tool to assess and show progress and trends towards an objective and target.

Though a large amount of literature has been consulted, any specific methodology to establish KPIs has not been found. It seems to there not be a unique procedure. Despite these facts, some indicators have been chosen as KPIs in PolynSPIRE project according to their relationship with marine litter impacts. They are numbered in Table 11:

Table 11. KPIs for the assessment of plastic waste leakages.

KPIs indicators	
Ecoefficiency KPIs	
Environmental indicators	**Economic indicators**
Climate change	Net added value
Marine ecotoxicity	Return on investment
Natural land transformation	LCC
Bioaccumulation	
Industrial symbiosis indicators	
Industrial symbiosis indicator	
Industrial environmental impact	
Resilience indicator	
Circular economy indicators	
Resource productivity	Trade in recyclable raw materials
Product utility	Patents
Citizens who have chosen alternatives to buying new products	Material circularity indicator.

6 BEST PRACTICES AND CIRCULAR ECONOMY ASSESSMENT METHODS CURRENTLY AVAILABLE

6.1 BEST PRACTICES

In the EU, climate change and environmental problems suppose one of the main worries of the population and one of the most important issues to face for Governments. For this end, it is necessary to perform a transition from conventional into circular economy.

By these reasons, the European Commission elaborated some documents in which were collected the most respectful industrial processes -from an environmental point of view-. These documents are called "BREF documents" and they describe the "Best Available Techniques" on the market (BATs).

In the next sections, the BATs relative to production of polymers, waste incineration and waste treatment are summarized, in order to have a global vision about European good practices in those areas related to the project.

Good practices on polymers production.

The specific BREF document about Production of Polymers divides the BATs in different categories, depending on the type of plastic produced. For polynSPIRE project, the most relevant are those described below [95].

Generic BATs for the production of polymers:

They are referred to every kind of polymers production process, and are:

1. Implementation of an Environmental Management System (EMSs). EMSs must contain:
    a. An environmental policy.
    b. Planification and establishment of the necessary procedures.
    c. Implementation of the procedures.
    d. Checking performance and corrective actions.
    e. Review by top management.
2. Reduction of fugitive emissions by advanced equipment design, e.g:
    a. Use of valves with bellow or double packing seals or equally efficient equipment.
    b. Magnetically driven or canned pumps, or pumps with double seals and a liquid barrier.
    c. Magnetically driven or canned compressors, or compressors using double seals and a liquid barrier
    d. Magnetically driven or canned agitators, or agitators with double seals and a liquid barrier.
    e. Minimisation of the number of flanges.
    f. Effective gaskets.
    g. Closed sampling systems.
    h. Drainage of contaminated effluents in closed systems.
    i. Collection of vents.
3. Assessment and measurement of fugitive loss to classify components in terms of type, service and process conditions.

4. Establishment and maintenance of an equipment monitoring and maintenance (M&M) and/or leak detection and repair (LDAR) programme.
5. Reduction of dust emissions with a combination of the following techniques:
    a. Dense phase conveying.
    b. Reduction of velocities in dilute phase conveying systems to as low as possible.
    c. Surface treatment and proper alignment of pipes in conveying lines.
    d. Use of cyclones and/or filters in the air exhausts of dedusting units.
    e. Use of wet scrubbers.
6. Minimization of plant start-ups and stops to avoid peak emissions and reduce consumption.
7. Secure the reactor contents in case of emergency stops.
8. Recyclability of the contained material from BAT 7 or to use it as fuel.
9. Prevention of water pollution by appropriate piping design and materials.
10. Separation of effluent collection systems for contaminated process effluent water, potentially contaminated water from leaks and other sources and uncontaminated water.
11. Treatment of the air purge flows coming from degassing silos and reactor vents.
12. Use of flaring systems to treat discontinuous emissions from the reactor system.
13. Use, where possible, power and steam from cogeneration plants.
14. Recovery of the reaction heat through the generation of low-pressure steam in processes or plants where internal or external consumers of the low-pressure steam are available.
15. Re-use of the potential waste from a polymer plant.
16. Use of pigging systems in multiproduct plants with liquid raw materials and products.
17. Use of a buffer for wastewater upstream of the wastewater treatment plant to achieve a constant quality of the wastewater.
18. Treatment of wastewater.

BAT for the production of polyamides.

In addition to the generic BATs, for the production of polyamides, the treatment of flue-gases from polyamide production process by wet scrubbing can be added.

Good practices on waste incineration.

BREF document about waste incineration has an extensive list of good practices on the subject. However, in the case of polynSPIRE project, only those ones related to plastics are applicable, i.e., selected municipal waste incineration. They consist in [96]:

1. The storage of wastes in enclosed hoppers or on sealed surfaces with controlled drainage inside covered and walled buildings.
2. When waste is stockpiled. it should generally be baled or otherwise prepared for such storage.
3. The generation of, at least, 0.6 – 1.0 MWh electricity/tonne of waste or the annual average electricity demand of the entire installation, including on-site waste pretreatment and on-site residue treatment operations
4. The location of new installations so that, as well as the 0.6 – 1.0 MWhe/ tonne of electricity generated, the heat and/or steam can also be utilised for CHP, so that in general an additional thermal export level of 0.5 – 1.25 MWh/tonne of waste can be achieved, or, where electricity is not generated, a thermal export level of 3 MWh/tonne of waste can be achieved.

5. Reduction of installation energy demand achievement of an average installation electrical demand (excluding pretreatment or residue treatment) to generally below 0.2 MWh/tonne of waste processed based on an average NCV of 4.2 MWh/tonne of waste.

Good practices on waste treatment.

As in the case of waste incineration, the specific BREF document shows an extensive list of good practices on waste treatment, but only some of them are applicable to polynSPIRE project scope, concretely [97]:

- *Reuse of packaging BATs:* in order to reduce the quantity of waste sent for disposal, BAT is to maximize the reuse of packaging. Description Packaging is reused for containing waste, when it is in good condition and sufficiently clean. Some applicability restrictions derive from the risk of contamination of the waste posed by the reused packaging.

6.2 AVAILABLE TOOLS TO MEASURE PRODUCT CIRCULARITY

Besides the best practices published by the European Commission focussed on the polymers production and its managing at the end of its useful lifetime, there are some tools able to measure the circularity of a specific product. In this line, this section contains a summary of three of the most important tools currently available, highlighting the advantages and disadvantages of each of them.

6.2.1 Circular Economy Toolkit (CET)

The Circular Economy Toolkit (CET) [30] is a free and online assessment tool to identify potential improvement of product's circularity. The user has to answer 33 questions in a ternary format (yes/partly/no or high/medium/low) divided into 7 categories: 7 questions related to design, manufacture and distribute; 3 related to usage; 6 related to maintenance and repair of the product; 3 related to reuse and redistribution of the product; 10 related to refurbish and remanufacture; 2 related to product-as-a-service; 2 related to product recycling at end-of-life [29].

6.2.2 Material Circularity Indicator (MCI)

The Material Circularity Indicator (MCI) was described by the Ellen MacArthur Foundation [25] as a tool for European companies to assess their products and business models performance in a context of circular economy. This tool is based on an Excel calculation sheet available online for free and can be used to evaluate product design but also for internal reporting or for procurement and investment decisions. To assess the circularity performance of the product, a spreadsheet tool is provided to include multiples materials as well as some advices on normalizing factors for individual product weight (such as revenues, product mass, and raw materials costs). The Material Circularity Indicator (MCI) gives a single score between 0 and 1 where higher values show a higher circularity [29].

6.2.3 Circular Economy Indicator Prototype (CEIP)

The Circular Economy Indicator Prototype (CEIP) was developed by Griffiths and Cayzer [29] to assess product performance in the context of circular economy. The CEIP is also based on an Excel calculation sheet and uses a points-based questionnaire. The questionnaire consists of 15 questions divided into 5 lifecycle stages: design or redesign; manufacturing; commercialisation; usage; and end-of-life. Once completed, the tool results in an overall score of the product circularity performance and a spider diagram which shows circularity performance across different parts of the lifecycle [29].

Table 12. Tools description, characteristics and operating mode [29]

Tools Characteristics	Circular Economy Toolkit (CET)	Material Circular Indicator (MCI)	Circular Economy Indicator Prototype (CEIP)
Description	It is an assessment tool to identify potential improvement of products' circularity.	It aims at helping companies to measure their transition towards a circular economy.	The CEIP aims at evaluating product performance in the context of circular economy.
Platform Support	Dynamic Webpage	Excel Spreadsheet	Excel Spreadsheet
Inputs	33 trinary-based questions divided into 7 sub-categories related to lifecycle stages.	Different percentages (reused, recycling) about material origin (feedstock) and destination (after use).	15 weighted questions divided into 5 lifecycle stages.
Outputs	Qualitative: Improvement potential at 3 level (high, medium, low) for every of the 7 sub-categories.	Quantitative: The MCI, single score, gives a value between 0 and 1 where higher values indicate a higher circularity.	Quantitative: The CEIP score (%) and a radar diagram showing aggregated score for each lifecycle stage.

6.2.4 Advantages of circular economy assessment tools

These tools have common advantages [29] such as: they are easy to use, even for those who are not specialists in circular economy; and provide a fast overview of product circularity performance.

Focusing on the strengths of each one, CET is a useful tool to provide a first trend of improvement opportunities. The consideration of the business opportunity and product design to carry out the qualitative assessment of the product, is the principal advantage. This tool also evaluates business opportunities (including financial viability and market growth potential) through possible extensions -according to inputs provided- of following services: maintain/repair, reuse/redistribute, refurbish/remanufacture and products as a service. The CET online platform is easy to understand for non-expert users in circular economy.

MCI is a practical tool to assess flow material potential of products circularity without lot of inputs data. Industrial practitioners could use it to compare product circularity performance with different material combinations.

The main advantages of CEIP are ease of use, simplicity, speed, and the fact it could be used as an effective metaphor for the diffusion of circular economy principles in industrial practices.

6.2.5 Disadvantages of circular economy assessment tools

However, all these tools have some weaknesses and limitations in the measurement of product circularity [29].

First, CET is a too superficial toolkit to carry out a real evaluation of the circular economy, so it is considered as a qualitative environmental assessment, based in a trinary questionnaire. With the ternary scale, when a question has an unclear interpretation, the user has the habit to put the cursor in the middle.

On the other hand, to evaluate circularity of a given company or product, the MCI is not enough by itself. MCI only considers the material scale contained in products or components, so several essential aspects for an efficient circular model (such as modularity, upgradability, connectivity, easy disassembly or design for preventive maintenance of products) are not taken into consideration. Interactions with other components (optimizing systems rather than components is the one of the key paradigms of circular economy) are not considered. Collaborations between stakeholders, inside the actors' network, or reverse

logistic, which are also crucial elements for a strong and functioning circular economy are either not taken into consideration. Also, the MCI does not favour closed loop beyond recycling and reuse, such as remanufacturing or refurbishment. It is assumed that the mass of the product does not change from manufacture to the end of use, which means that product is not consumed, degraded or lost during its use.

Finally, the CEIP interpretation through a single score do not encompass the true circular economy complexity. The binary scoring system used could be quite deficient for some questions. Authors of the CEIP acknowledge a superficial commitment with decision-makers and that the reliability of the questionnaire is based on the case study specific context: the 15 questions are mainly focused on the manufacturing and end-of-life stages of the product lifecycle, and therefore neglect certainly other circular economy crucial aspects. Indeed, several important aspects for an efficient circular economy are not taken into account such as, modularity, design for disassembly, upgradability, used of new technology or connected devices: for instance, sensors to enable product traceability.

In summary, these tools can provide a first and rapid overview of product circularity performance. However, they do not consider all aspects of the circular economy and miss some important elements. For this reason, it is necessary to improve the existing tools to assess product circularity performance.

6.3 FP7 AND H2020 PROJECTS

Besides the best practices and the circular economy assessment tools indicated in the previous section, some EU funded research projects have been identified as innovative actions since its objective is to improve some parts of the plastic value chain, to develop new assessment methodologies or to impulse the plastic sector through a more circular economy. As a summary, EU projects with potential synergies with polynSPIRE are the following ones:

- BIOCLEAN
- CLEANSEA
- PEGASO
- Plasticircle
- VORTEX
- MARMICROTOX
- CIRC-PACK
- iCAREplast
- EFFECTIVE
- EMBRACED
- DEMETO
- BARBARA
- CloseWEE
- CO-PILOT
- URBANREC
- RESYNTEX
- ISOPREP

A short summary of some of those projects can be found in ANNEX. Each project has a datasheet where the following information is contained: full name of the project, website, logo, financing programme, duration, partners involved, objective and main results.

7 GUIDELINES AND CONCLUSIONS FROM THE LITERATURE REVIEW

Summary of potential barriers of existing CE practices and Marine Litter mitigation

Tough circular economy is the ideal scenario for environmental protection and sustainable development, it still presents some limitations. In the concrete case of plastic sector in the EU, the main ones are [11]:

- From the 25.5 million tonnes of plastic waste generated in the EU every year, less than 30% of them are collected for recycling.
- A significant amount of the recycled part leaves the EU to be treated in third countries, where different environmental standards are applied.
- Low profitability of the plastic recycling industry: demand for recycled plastics today accounts for only around 6 % of plastics demand in Europe. In recent years, the EU plastic recycling sector has suffered from low commodity prices and uncertainties.
- Very large quantities of plastic waste leak into the environment, generating significant economic and environmental damage. Globally, 5 to 13 million tonnes of plastics — 1.5 to 4 % of global plastics production — end up in the oceans every year. In fact, plastic accounts for over 80 % of marine litter. UNEP estimates that damage to marine environments is at least USD 8 billion per year globally.
- In the EU, 150,000 to 500,000 tonnes of plastic waste enter the oceans every year. This represents a small proportion of global marine litter. Yet, plastic waste from European sources ends up in particularly vulnerable marine areas, such as the Mediterranean Sea and parts of the Arctic Ocean.
- New kinds of plastics dangers: such as microplastics, that are tiny fragments of plastic (<5mm). They end up at sea, where are ingested by marine fauna -due to their small size- and introduced into the food chain.

In spite of these facts, an efficient circular economy is possible. To reach it, it is necessary to adopt a strategic vision, concerning on how circular plastics in some decades should be ahead. For this, it is necessary to promote investments in innovative solutions, such as polynSPIRE to turn challenges into opportunities.

Overview of indicators to assess circular economy

Another objective of this deliverable, which is the establishment of an exhaustive and ad-hoc KPI list, accompanied by their method of calculation, is proposed for its application in polynSPIRE project. The guideline developed in this document can be replicated for similar future projects regarding plastic waste and marine litter. The most relevant KPIs have been selected to set objective criteria considering quantitative and qualitative aspects about circular economy, industrial symbiosis, and ecoefficiency. The KPI selection aims at guiding decision makers regarding the potential implications of the implementation of polynSPIRE innovations. The procedure to score the indicators selected within each indicator set is presented and discussed for an appropriate and significant application. This can be regarded as an “alive” list, since it can be updated along the development of the project, in case any further adjustment is needed.

Best practices and methods to assess circular economy

A collection of the best practices proposed by the European Commission, whose application could improve the circularity of sectors based on plastics, has been presented in this deliverable. Practices has been divided into those related to polymers production, waste incineration or waste treatment. Besides, available tools to quantify circularity of a system and to facilitate circular economy designs have been reported. Some of these tools are Material Circular Indicator (MCI), Circular Economy Toolkit (CET) and Circular Economy Indicator Prototype (CEIP). Each tool has different degree of complexity, so their suitability will depend on the scope of the objectives that want to be achieve with their application. Furthermore, many EU funded projects related to circular economy and mitigation of marine litter have been identified and included as innovative actions towards a more sustainable economy.

8 DEVIATIONS

No deviations have been registered during the development or this deliverable.

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BIBLIOGRAPHY / REFERENCES

[1] Gmark Consulting, "Report on Maize Value Chain," Dhaka, Bangladesh, 2013.

[2] M. E. Porter, *Competitive Advantage: Creating and Sustaining Superior Performance*. New York: The Free Press, 1998.

[3] M. Kirli and H. Gümüs, "The implementation of strategic management accounting based on value chain analysis: value chain accounting," *Int. J. Soc. Sci. Humanit. Stud.*, vol. 3, no. 1, pp. 307–321, 2011.

[4] D. Buxton, R. Farr, and B. Maccarthy, "State of the art review of value chain mapping techniques relevant to the aerospace industry," *Vivace Consort.*, vol. 2, 2005.

[5] A. Shrivastava, "Introduction to Plastics Engineering," in *Introduction to Plastics Engineering*, 2018.

[6] K. L. Law, "Plastics in the Marine Environment," *Ann. Rev. Mar. Sci.*, vol. 9, no. 1, pp. 205–229, 2017.

[7] UNEP & GRID, "Marine Litter Vital Graphics. United Nations Environment Programme and GRID-Arendal. Nairobi and Arendal.," 2016.

[8] Plastics Europe: Association of Plastic Manufacturers, "The facts 2018: An Analysis of European Plastics Production, Demand and Waste Data.," Brussels, 2018.

[9] Science History Institute, "Science of Plastics." [Online]. Available: https://www.sciencehistory.org/science-of-plastics. [Accessed: 16-May-2019].

[10] American Chemistry Council, "Lifecycle of a plastic product." [Online]. Available: https://plastics.americanchemistry.com/Lifecycle-of-a-Plastic-Product/. [Accessed: 28-May-2019].

[11] European Commission, "A European Strategy for Plastics in a Circular Economy," Brussels, 2018.

[12] Green Schools Programme, "Waste." [Online]. Available: http://www.greenschoolsprogramme.org/knowledge-bank/waste/. [Accessed: 16-May-2019].

[13] S. Van der Berg, "Creating inclusive value chains in plastic waste management is paramount for a green economy," *SEED*, 2015. .

[14] European Commision, "Our Oceans, Seas and Coast. Descriptor 10: Marine Litter," 2018. [Online]. Available: http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/index_en.htm. [Accessed: 24-May-2019].

[15] European Commision, "Towards a circular economy: A zero waste programme for Europe," Brussels, 2014.

[16] Ellen McArthur Foundation, "The new plastics economy. Rethinking the future of plastics," 2016.

[17] A. W. Mueller, "A value chain analysis of cardboard collection in inner city durba, South Africa," 2005.

[18] M. Will, M. Vogelzang, M. Wanyonyi, and H. Hoeffler, "Capacity Development Concept for Value Chain Development," 2008.

[19] R. Staffeld, "Value Chain Analysis in the Plastic Recycling Sector in Cairo and Alexandria.," Eschborn,

2010.

[20] R. Jaligot, D. C. Wilson, C. R. Cheeseman, B. Shaker, and J. Stretz, "Resources , Conservation and Recycling Applying value chain analysis to informal sector recycling : A case study of the Zabaleen," *"Resources, Conserv. Recycl.*, vol. 114, pp. 80–91, 2016.

[21] B. Simon, "Resources , Conservation & Recycling. What are the most significant aspects of supporting the circular economy in the plastic industry?," *Resour. Conserv. Recycl.*, vol. 141, no. November 2018, pp. 299–300, 2019.

[22] M. K. Eriksen, K. Pivnenko, M. E. Olsson, and T. F. Astrup, "Contamination in plastic recycling: Influence of metals on the quality of reprocessed plastic," *Waste Manag.*, vol. 79, pp. 595–606, 2018.

[23] L. Milios, L. Holm, D. Mckinnon, C. Christensen, M. Katrine, and M. Hallstrøm, "Plastic recycling in the Nordics : A value chain market analysis," *Waste Manag.*, vol. 76, pp. 180–189, 2018.

[24] European Commission, "The European Commission's science and knowledge service Joint Research Centre. Evaluation of its relations with industry - Estudio," 2017. .

[25] Ellen MacArthur Foundation, "Circularity Indicators: An Approach to Measure Circularity. Methodology & Project Overview," Cowes, UK, 2015.

[26] V. Elia, M. G. Gnoni, and F. Tornese, "Measuring circular economy strategies through index methods: A critical analysis," *J. Clean. Prod.*, vol. 142, pp. 2741–2751, 2017.

[27] Ellen McArthur Foundation, "Towards the Circular Economy - Economic and Business Rationale for an Accelerated Transition," 2013.

[28] European Environment Agency (EEA), "Circular economy in Europe Developing the knowledge base," European Environmental Agency, 2016.

[29] M. Saidani, B. Yannou, Y. Leroy, and F. Cluzel, "How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework," *Recycling*, vol. 2, no. 1, p. 6, Mar. 2017.

[30] J. Evans and N. Bocken, "The Circular Economy Toolkit." [Online]. Available: http://circulareconomytoolkit.org/.

[31] S. Cayzer, P. Griffiths, and V. Beghetto, "Design of indicators for measuring product performance in the circular economy," *Int. J. Sustain. Eng.*, vol. 7038, no. June, pp. 1–10, 2017.

[32] Y. Kalmykova, M. Sadagopan, and L. Rosado, "Resources , Conservation & Recycling Circular economy – From review of theories and practices to development of implementation tools," *Resour. Conserv. Recycl.*, vol. 135, no. February 2017, pp. 190–201, 2018.

[33] UNEP (United Nations Environment Programme), "Life Cycle Initiative." [Online]. Available: https://www.unenvironment.org/explore-topics/resource-efficiency/what-we-do/life-cycle-initiative. [Accessed: 27-May-2019].

[34] UNEP/SETAC, "Life cycle management: how business uses it to decrease footprint, create opportunities and make value chains more sustainable," Paris, France, 2009.

[35] M. Niero and X. C. Schmidt, "The Role of Life Cycle Sustainability Assessment in the Implementation

of Circular Economy Principles in Organizations," *Procedia CIRP*, vol. 69, no. May, pp. 793–798, 2018.

[36] UNEP/SETAC, "Guidelines for Social Life Cycle Assessment of Products," Belgium, 2009.

[37] European Commission, "Indicators to measure Social Protection Performance," Brussels, 2017.

[38] United Nations Development Programme (UNDP), "Handbook on Planning, Monitoring and Evaluating," 2009.

[39] T. Srebotnjak, H. Gerdes, A. Best, and S. Cavalieri, "Evaluation of Indicators for EU Policy Objectives," Berlin, 2009.

[40] European Commission, "Resource Efficiency Indicators," Brussels, 2015.

[41] M. Saidani, B. Yannou, Y. Leroy, F. Cluzel, and A. Kendall, "A taxonomy of circular economy indicators," *J. Clean. Prod.*, vol. 207, pp. 542–559, Jan. 2019.

[42] L. Manning, "Systems for Sustainability and Transparency of Food Supply Chains," *Sustain. Food Syst. from Agric. to Ind.*, pp. 153–187, Jan. 2018.

[43] S. Huysveld, S. Hubo, K. Ragaert, and J. Dewulf, "Advancing circular economy benefit indicators and application on open-loop recycling of mixed and contaminated plastic waste fractions," *J. Clean. Prod.*, vol. 211, pp. 1–13, Feb. 2019.

[44] A. J. Lennie, J., Tacchi, J., Koirala, B., Wilmore, M., & Skuse, "Equal Access Participatory Monitoring and Evaluation toolkit: Setting objectives and indicators," 2011.

[45] F. Figge, A. S. Thorpe, P. Givry, L. Canning, and E. Franklin-Johnson, "Longevity and Circularity as Indicators of Eco-Efficient Resource Use in the Circular Economy," *Ecol. Econ.*, vol. 150, pp. 297–306, Aug. 2018.

[46] J. Mesa, I. Esparragoza, and H. Maury, "Developing a set of sustainability indicators for product families based on the circular economy model," *J. Clean. Prod.*, vol. 196, pp. 1429–1442, Sep. 2018.

[47] M. Niero and P. P. Kalbar, "Coupling material circularity indicators and life cycle based indicators: A proposal to advance the assessment of circular economy strategies at the product level," *Resour. Conserv. Recycl.*, vol. 140, pp. 305–312, Jan. 2019.

[48] United Nations ESCAP and Greening of Economic Green Science, "Eco-efficiency Indicators: Measuring Resource-use Efficiency and the Impact of Economic Activities on the Environment," 2009.

[49] European Environmental Agency (EEA), "Technical report No 8/2014 - Digest of EEA indicators," 2014.

[50] European Environmental Agency (EEA), "EEA core set of indicators - GUIDE," Luxembourg, 2015.

[51] United Nations (UN), "TRANSFORMING OUR WORLD: The 2030 Agenda for Sustainable Development," 2015.

[52] SETAC, "Society of Environmental Toxicology and Chemistry," 2017. .

[53] International Organization for Standardization, "ISO 14040:2006, Environmental Management - Life Cycle Assessment - Principles and Framework." Geneve, Switzerland, 2006.

[54] M. Goedkoop, R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, and R. Van Zelm, "ReCiPe: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level," 2008.

[55] European Environment Agency (EEA), "Environmental Indicator Report 2016-in support to the monitoring of the 7th Environment Action Programme," 2016.

[56] H. Estevan and B. Schaefer, "Life Cycle Costing - state of the art report," 2017.

[57] T. E. Graedel and B. R. Allenby, "Industrial Ecology," *Ellen MacArthur Foundation*. .

[58] European Green Capital Project, "Industrial Symbiosis," 2017.

[59] G. C. Mantese and D. C. Amaral, "Agent-based simulation to evaluate and categorize industrial symbiosis indicators," *J. Clean. Prod.*, vol. 186, pp. 450–464, Jun. 2018.

[60] M. Felicio, D. Amaral, K. Esposto, and X. Gabarrell Durany, "Industrial symbiosis indicators to manage eco-industrial parks as dynamic systems," *J. Clean. Prod.*, vol. 118, pp. 54–64, Apr. 2016.

[61] C. Hardy and T. E. Graedel, "Industrial ecosystems as food webs," *J. Ind. Ecol.*, 2002.

[62] H.-S. Park and S. K. Behera, "Methodological aspects of applying eco-efficiency indicators to industrial symbiosis networks," *J. Clean. Prod.*, vol. 64, pp. 478–485, Feb. 2014.

[63] N. Trokanas, F. Cecelja, and T. Raafat, "Semantic approach for pre-assessment of environmental indicators in Industrial Symbiosis," *J. Clean. Prod.*, 2015.

[64] G. Valenzuela-Venegas *et al.*, "A resilience indicator for Eco-Industrial Parks," *J. Clean. Prod.*, 2018.

[65] C. Adelle and M. Pallemaerts, "Sustainable development Indicators-An Overview of relevant FP funded research and identification of further needs in view of EU and international activities," *Agric. Econ. (Czech Republic)*, vol. 59, no. 2, pp. 74–80, 2013.

[66] C. Böhringer and P. E. Jochem, "Measuring the immeasurable—A survey of sustainability indices," *Ecol. Econ.*, vol. 63, no. 1, pp. 1–8, 2007.

[67] G. Couto Mantese and D. Capaldo Amaral, "Comparison of industrial symbiosis indicators through agent-based modeling," *J. Clean. Prod.*, 2017.

[68] European Commission, "Indicator results across the priority objectives in a scoreboard." .

[69] EASAC - European Academies' Science Advisory Council, "Indicators for a circular economy," Halle (Germany), 2016.

[70] European Commission, "Circular Economy Indicators- Eco-innovation Action Plan." [Online]. Available: https://ec.europa.eu/environment/ecoap/indicators/circular-economy-indicators_en. [Accessed: 20-May-2019].

[71] European Commision, "Investing in a smart, innovative and sustainable Industry," Brussels, 2017.

[72] European Commission, "Circular Economy Monitoring Framework," Strasbourg, 2018.

[73] European Commission, "Report on Critical Raw Materials and the Circular Economy," Brussels, 2018.

[74] Eurostat, "Circular Economy Indicators." [Online]. Available:

https://ec.europa.eu/eurostat/web/circular-economy/indicators/monitoring-framework. [Accessed: 22-May-2019].

[75] S. Huysman, J. De Schaepmeester, K. Ragaert, J. Dewulf, and S. De Meester, "Performance indicators for a circular economy: A case study on post-industrial plastic waste," *Resour. Conserv. Recycl.*, vol. 120, pp. 46–54, May 2017.

[76] European Commission, "Roadmap to Resource Efficient Europe," Brussels, 2011.

[77] F. Di Maio, P. C. Rem, K. Baldé, and M. Polder, "Measuring resource efficiency and circular economy: A market value approach," *Resour. Conserv. Recycl.*, vol. 122, pp. 163–171, Jul. 2017.

[78] E. Franklin-Johnson, F. Figge, and L. Canning, "Resource duration as a managerial indicator for Circular Economy performance," *J. Clean. Prod.*, vol. 133, pp. 589–598, Oct. 2016.

[79] UNEP and NOAA, "The Honolulu Strategy: A global framework for prevention and management of marine debris," 2012.

[80] A. Löhr, H. Savelli, R. Beunen, M. Kalz, A. Ragas, and F. Van Belleghem, "Solutions for global marine litter pollution," *Curr. Opin. Environ. Sustain.*, vol. 28, pp. 90–99, 2017.

[81] E. Rojo-Nieto and T. Montoto, *Basuras marinas, plásticos y microplásticos: orígenes, impactos y consecuencias de una amenaza global*, no. January. 2017.

[82] UNEP (United Nations Environment Programme), "Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change," 2016.

[83] F. Gallo *et al.*, "Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures," *Environmental Sciences Europe*, vol. 30, no. 1. 2018.

[84] J. R. Jambeck *et al.*, "Plastic waste inputs from land into the ocean," *Science (80-.).*, 2015.

[85] L. C. M. Lebreton, J. Van Der Zwet, J. W. Damsteeg, B. Slat, A. Andrady, and J. Reisser, "River plastic emissions to the world's oceans," *Nat. Commun.*, vol. 8, pp. 1–10, 2017.

[86] NOAA (US National Oceanic and Atmospheric Administration), "Debunking the Myths about Garbage Patches." .

[87] S. C. Gall and R. C. Thompson, "The impact of debris on marine life.," *Mar. Pollut. Bull.*, vol. 92, no. 1–2, pp. 170–179, 2015.

[88] M. Bergmann, L. Gutow, and M. Klages, *Marine anthropogenic litter*. 2015.

[89] L. Van Cauwenberghe and C. R. Janssen, "Microplastics in bivalves cultured for human consumption," *Environ. Pollut.*, 2014.

[90] S. Kühn, E. L. Bravo Rebolledo, and J. A. Van Franeker, "Deleterious effects of litter on marine life," in *Marine Anthropogenic Litter*, 2015.

[91] The Secretariat of Convention on Biological Diversity, *Marine debris: Understanding, preventing and mitigating the significant adverse impacts on marine and coastal biodiversity*. 2016.

[92] M. C. Fossi *et al.*, "Bioindicators for monitoring marine litter ingestion and its impacts on Mediterranean biodiversity," *Environmental Pollution*. 2018.

[93] European Commission and DG Environment, "Assessment of resource efficiency indicators and targets. Final report," 2012.

[94] N. Eisenmenger *et al.*, "Towards a Conceptual Framework for Social-Ecological Systems Integrating Biodiversity and Ecosystem Services with Resource Efficiency Indicators," *Sustainability*, vol. 8, no. 3, p. 201, 2016.

[95] European Commission, "Reference Document on Best Available Techniques in the Production of Polymers," 2007.

[96] European Commission, "Reference Document for the best available techniques for Waste incineration," 2006.

[97] European Commission, "Best Available Techniques (BAT) Reference Document for Waste Treatment," 2018.

ANNEX

Project title	BIOCLEAN: New BIOtechnologiCaL approaches for biodegrading and promoting the environmEntal biotrAnsformation of syNthetic polymeric materials
Website	http://www.biocleanproject.eu
Logo	
Programme	FP7-KBBE - Specific Programme "Cooperation": Food, Agriculture and Biotechnology Grant agreement ID: 312100
Duration	1 September 2012 - 31 August 2015
Partners	- ALMA Mater Studiorum - Università di Bologna - Internationales Hochschulinstitut Zittau - Fachhochschule nordwestschweiz - Polytechneio KRITIS - Helmholtz-zentrum fur Umweltforschung GMBH – UFZ - MADEP SA - Technische Universitaet Dresden - Ostravska Univerzita - Centre National de la Recherche Scientifique CNRS - Centrum Materialow Polimerowych Iweglowych Polska Akademia NAUK*CMPIW PAN - Organic waste systems NV - Felsilab srl - Biobasic Environnement SARL - Techniki Prostasias Perivallontos Anonymi Etaireia - NANJING University - Diadimotiki Epicheirisi Diacheirisis Stereon Apovliton Anonymi Etaireia OTA - Maritim Miljo Beredskap AS - Plasticseurope - SIMA-TEC GMBH - Havforskningsinstituttet
Objective	In BIOCLEAN project, novel and robust microorganisms (aerobic and anaerobic bacteria, and fungi) able to extensively degrade polyethylene (PE), polypropylene (PP), polystyrol (PS) and polyvinyl chloride (PVC) polymers and plastics will be isolated from actual-site aged plastic wastes obtained from several European marine and terrestrial sites, composting facilities and landfills, and obtained via tailored screenings from existing European collections of microbes. Robust enzymes able to fragment the target plastics with the production of valuable chemicals and building blocks will be obtained from the selected microbes and enzyme collections. Untreated and

	physically/chemically pre-treated PE, PS, PP and PVC polymers and plastics will be employed in such isolation/ screening activities, and an integrated methodology, relying on advanced analytical methods (determining plastics physicochemical changes and breakdown products resulting from biological attack), and tailored enzymatic, microbiological and ecotoxicological methods, will be adopted for the characterization of actual industrial relevance of the obtained microbes and enzymes. Physical and chemical pretreatments improving biodegradability of target plastics will be identified and transferred on the pilot scale. The most promising microbial cultures and enzymes will be exploited in the development of pilot scale, slurry or solid-phase bioprocesses for the bioremediation and controlled depolymerization, respectively, of target pretreated plastics and in the set up of tailored bioaugmentation protocols for enhancing plastic waste biodegradation in marine water systems, composting and anaerobic digestor facilities. The processes developed will be assessed for their economic and environmental sustainability. Field scale validation of the most promising bioaugmentation protocols in a composting and a marine site and attempts to develop a plastic pollution reduction strategy for the Aegean Sea have been planned too.
Main Results	Plastic is a material that has revolutionised modern life, however, its irresponsible usage can have damaging environmental impacts, often as a result of poor waste management and littering. While plastic is designed for durability, its long term degradation is not yet fully understood. The BIOCLEAN (New Biotechnological approaches for biodegrading and promoting the environmental biotransformation of synthetic polymeric materials) project was established to address this challenge. The consortium isolated microbes from a variety of actual-site aged plastic wastes. These were retrieved from the Aegean Sea and Norwegian Sea and a variety of European landfills, composting facilities, anaerobic waste treatment plants and an industrial production plant Furthermore microbes from culture collections were investigated. Researchers also explored the feasibility of biotechnologies for breakdown, detoxification and valorisation of plastic waste. Furthermore, the project sought to enhance natural biodegradation of plastics in organic waste composting and bio-gasification facilities. It also aimed to mitigate the effects of plastic pollution on marine environments. Laboratory results were scaled up for a range of different plastics and tested in the municipal composting facility of Chania (Crete, Greece) and in the Aegean sea. Researchers investigated the use of microorganisms and enzymes to degrade different plastics and assessed a collection of 65 bacteria, including those from marine origin and fungi that were shown to be able to partially degrade plastic films. The microbes can be patented by the project partners and described in scientific publications and used to develop tailored processes that will help protect the environment or valorise waste plastics. New pilot-scale biological and hybrid chemical/physical-biological processes were developed by BIOCLEAN. These were able to partially degrade polyvinyl chloride (PVC) films and to a lesser extent polyethylene (PE) and polypropylene (PP) plastic films. The consortium also developed lab and pilot-scale bioaugmentation protocols for intensifying the biodegradation of (micro) plastics in soil, composting and anaerobic waste treatment facilities and in the marine environment. BIOCLEAN contributed to clarify that assisting the gradual transition of the plastic sector towards a market consisting of fully recyclable (bio) plastics and plastics fully biodegradable/compostable in terrestrial and marine environments is the only

	strategy to significantly reduce the current environmental impact of the EU oil-based plastic sector.

Project title	CLEANSEA: Towards a Clean, Litter-Free European Marine Environment through Scientific Evidence, Innovative Tools and Good Governance
Website	https://cleanseaproject.wordpress.com/
Logo	
Programme	FP7-ENVIRONMENT - Specific Programme "Cooperation": Environment (including Climate Change) Grant agreement ID: 308370
Duration	1 January 2013 - 31 December 2015
Partners	- Stichting VU - CORPUS DATA MINING HANDELSBOLAG - UNIVERSITY OF EXETER - Centro Mediterraneo de estudios para el uso y conservacion de las costas - Stichting Deltares - KIMO Nederland en Belgie - Eigen Vermogen Van Het Instituut Voor Landbouw en Visserijonderzoek - Denkstatt Bulgaria OOD - Orebro University - Panepistimio AIGAIOU - Norsk Institutt for Luftforskning Stiftelse - Corpus Data & IMAGE ANALYSIS AB - Callisto productions LTD - KC DENMARK AS - Ecologic Institut Gemeinnützige GmbH - WOLTHUIS YVONNE BARBARA - Institutul National de cercetare-dezvoltare marina grigore antipa - Hellenic Centre for marine research
Objective	There is an urgent need for an improved knowledge base for the management of marine litter. CLEANSEA aims to generate new information on the impacts (biological, social and economic) of marine litter, develop novel tools needed to collect and monitor litter and protocols needed for monitoring data (litter composition and quantities) and evaluate the impact of mitigation strategies and measures in order to provide options to policy makers in the EU. This will be achieved through 7 work packages. WPs 2 and 3 cover biological impacts and technical aspects of marine monitoring, monitoring tools and applications. WP4 investigates multilevel socio-economic impact and barriers to Good Environmental Status, providing a justification for the development of management measures and policy options in WP5. This WP combines advanced institutional analysis with a participatory approach in order to identify and assess management measures, strategies and policy options in collaboration with stakeholders that reduce marine litter and alleviate diverse ecological and socio-economic impacts as identified in WPs 2-4. WP6 will integrate the outcomes of the project and hosts the CLEANSEA Stakeholder Platform. Management is dealt with under WP1 with a professional dissemination package, including a documentary film, website, publications, etc. covered in WP7. CLEANSEA includes top

	scientific groups from eleven European countries distributed over all marine regions. It also includes six SMEs, four of them focused on technological innovation of monitoring, mitigation and recycling tools. CLEANSEA will tackle the marine litter problem from a broad interdisciplinary perspective. Advancement is expected in the array of monitoring tools and systems, knowledge about impacts, and management measures and policy options. By searching for new paradigms and integrating knowledge and methods, CLEANSEA intends to contribute concrete elements to the road map towards strong reductions in marine litter.
Main Results	A 2013 survey, conducted by Eurobarometer, found that more than 90 % of respondents were against litter reaching our oceans. They also expected more initiatives to limit waste and increase recycling. The EU-funded CLEANSEA project addressed many of these concerns as part of the Marine Strategy Framework Directive (MFSD). CLEANSEA researchers analysed the biological impact and technical aspects of marine monitoring. Based on this information, a novel microplastic sampler was designed and tested by sampling marine litter on the seabed. These samples were used as input for plastic fragmentation and hydrodynamic modelling studies. Another focus of the CLEANSEA project was to inform marine legislation and policies aimed at reducing waste. Researchers assessed the drivers for marine litter and developed an overview of the barriers to good environmental status. They also investigated the socioeconomic impact of reducing marine litter and are developing a database of the economic value of marine ecosystem services. CLEANSEA aimed to curb waste by creating more sustainable production and consumption patterns and improving recycling and waste management. This will help solve the oceans' litter problem, which in turn contributes to a healthier environment.

Project title	PEGASO: People for Ecosystem Based Governance in Assessing Sustainable Development of Ocean and Coast
Website	https://cordis.europa.eu/project/rcn/94028/factsheet/en
Logo	
Programme	FP7-ENVIRONMENT - Specific Programme "Cooperation": Environment (including Climate Change) Grant agreement ID: 244170
Duration	1 February 2010 - 31 January 2014
Partners	- Universitat Autònoma de Barcelona - Universidad Pablo Olavide - Université de Bretagne Occidentale - University of Nottingham - Ca'Foscari University of Venice - Université de Genève - Université Mohammed V - Rabat Agdal - University of Balamand - French Research Institute for Exploration of the Sea - Hellenic Centre for Marine Research - Danube Delta National Institute for Research and Development - Marine Hydrophysical Institute-Ukrainian National Academy of Sciences - National Institute of Oceanography and Fisheries - National Authority for Remote Sensing and Space Sciences - Plan Bleu - Priority Action Programme/Regional Activity Centre PAP/RAC Croatia - Centre JRC - Black Sea Commission against pollution Permanent Secretariat - Intergovernmental Oceanographic Commission
Objective	Many efforts have been deployed for developing Integrated Coastal Zone Management (ICZM) in the Mediterranean and the Black Sea. Both basins have and continue to suffer severe environmental degradation. In many areas this has led to unsustainable trends, which have impacted, on economic activities and human well-being. An important progress has been made with the launch of the ICZM Protocol for the Mediterranean Sea in January 2008. The ICZM Protocol offers, for the first time in the Mediterranean, an opportunity to work in a new way, and a model that can be used as a basis for solving similar problems elsewhere, such as in the Back Sea. The aim of PEGASO is to build on existing capacities and develop common novel approaches to support integrated policies for the coastal, marine and maritime realms of the Mediterranean and Black Sea Basins in ways that are consistent with and relevant to the implementation of the ICZM Protocol for the Mediterranean. PEGASO will use the model of the existing ICZM Protocol for the Mediterranean and adjust it to the needs of the Black Sea through three innovative actions:

	- Constructing an ICZM governance platform as a bridge between scientist and end-user communities, going far beyond a conventional bridging. The building of a shared scientific and end users platform is at the heart of our proposal linked with new models of governance. -Refining and further developing efficient and easy to use tools for making sustainability assessments in the coastal zone (indicators, accounting methods and models, scenarios, socio-economic valuations, etc). They will be tested and validated in 10 sites (CASES) and by the ICZM Platform, using a multi-scale approach for integrated regional assessment. -Implementing a Spatial Data Infrastructure (SDI), following INSPIRE Directive, to organize local geonodes and standardize spatial data to support information sharing on an interactive visor, to make it available to the ICZM Platform, and to disseminate all results of the project to all interested parties and beyond. -Enhancing regional networks of scientists and stakeholders in ICPC countries, supported by capacity building, to implement the PEGASO tools and lessons learned, to assess the state and trends for coast and sea in both basins, identifying present and future main threats agreeing on responses to be done at different scales in an integrated approach, including transdisciplinary and transbondary long-term collaborations.
Main Results	The PEGASO project has supported the implementation of the Integrated Coastal Zone Management (ICZM) Protocol in the Mediterranean and has contributed to the development of similar policies in the Black Sea; it has bridged science and decision-making process along a collaborative process of work. PEGASO has also developed tools to better appraise conflicting issues, responding closely to different articles from the Protocol, focusing on the balance between urban developments versus natural capital maintenance. This reflexion has included the analysis of cumulative impacts of climate change and human activities, risk vulnerability and adaptation (indicators, Land and sea use maps, accounting methods, models and scenarios). Tools have been tested and validated in a multi-scale approach for integrated regional assessment through a number of relevant Collaborative Application Sites for Assessment (CASES). All the tools and methods are fully accessible at the PEGASO website and have served to produce indicators factsheets at different places, and an atlas for the Mediterranean and Black seas. Tools are very useful per se, but they have also served to develop participative methods for supporting decision making, facilitating a common understanding of the coastal and marine processes, getting a common understanding of which issues are manageable (or not), and in which way they should be managed, how stakeholders have to collaborate and at which scale, including cross-boundary collaborations. In brief, to assess what are the main priorities today, establishing road maps for actions towards a co-constructed desired future.

Project title	**Plasticircle: Improvement of the plastic packaging waste chain from a circular economy approach**
Website	https://www.sintef.no/en/projects/plasticircle-improvement-of-the-plastic-packaging-waste-chain-from-a-circular-economy-approach/ and https://ecp4.eu/projects/
Logo	PlastiCircle TOO VALUABLE TO WASTE
Programme	H2020 – CIRC-01-2016
Duration	2017-2021
Partners	- STIFTELSEN SINTEF, - PICVISA, - AXION RECYCLING LTD, - CENTRO RICERCHE FIAT SCPA, - GEMEENTE UTRECHT, - LAS NAVES, - MUNICIPALITY OF ALBA IULIA, - MESTNA OBCINA VELENJE, - SOCIEDAD ANONIMA AGRICULTORES DE LAVEGA DE VALENCIA, - POLARIS M HOLDING SRL, - INDUSTRIAS TERMOPLASTICAS VALENCIANAS, - Armacell Benelux S.A., - Imperbel N.V., - CONSORZIO PER LA PROMOZIONE DELLA CULTURA PLASTICA PROPLAST, - HAHN PLASTICS LTD, - ECOEMBALAJES ESPANA, S.A., - Fundacio Knowledge Innovation Market Barcelona, - PLASTICSEUROPE, - ICLEI EUROPEAN SECRETARIAT GMBH
Objective	The goal of PlastiCircle is to improve the Circular Economy of Plastics, applying a holistic process developed for the reintroduction of plastic packaging into the plastic value chain. The approach is based on innovation in the four stages associated with plastic packaging post-use treatment: collection, transport, sorting and recycling.
Main Results	Work in progress

Project title	VORTEX: Plastic in the Ocean: Microbial Transformation of an 'Unconventional' Carbon Substrate
Website	https://cordis.europa.eu/project/rcn/214724/factsheet/en
Logo	
Programme	H2020-EU.1.1. - EXCELLENT SCIENCE - European Research Council Grant agreement ID: 772923
Duration	1 June 2018 - 31 May 2023
Partners	STICHTING NEDERLANDSE WETENSCHAPPELIJK ONDERZOEK INSTITUTEN
Objective	Large quantities of plastics comprising a diverse set of hydrocarbon or hydrocarbon-like polymers are constantly released to the oceans. The impacts of plastics in marine environments are detrimental, as they are seemingly recalcitrant and harmful to marine life. The severity of this problem is gaining momentum because the untamed demand for plastics has led to an ever-increasing release of plastic to the sea. However, despite their seemingly persistent properties, they do not accumulate as expected, indicating a substantial sink for plastics in the ocean. Plastics are synthetic and thus rather new and 'unconventional' compounds in the marine realm, yet microbes can utilise plastics as carbon substrates. However, the potential for microbial degradation of plastics in the ocean as well as key factors controlling degradation kinetics are largely unknown and have been discussed controversially. Using innovative stable isotope assays, my preliminary research has shown that plastics can be degraded in marine sediments under aerobic as well as anaerobic conditions. Here I propose to further investigate the potential for marine plastic degradation by microbes in laboratory- and field-based experiments across a wide range of contrasting environmental boundary conditions. In the VORTEX project, we will use cutting-edge stable isotope labelling and stable isotope probing assays in combination with biogeochemical/microbiological and organic geochemical tools to trace isotopically labelled carbon from the plastic-substrate pools into microbial metabolites (e.g. CO2) and biomass (e.g. diagnostic lipid biomarkers, DNA/RNA). This will lead to a breakthrough in our understanding of microbial plastic degradation in the ocean because the proposed analytical approaches allow to quantify kinetics of microbial polymer breakdown, to identify and quantify the responsible microbes and degradation pathways, and to determine environmental conditions conducive for plastic degradation.
Main Results	Work in progress

Project title	MARMICROTOX: Marine microplastics toxicity: investigating microplastics and their co-contaminants in marine organisms
Website	
Logo	
Programme	FP7-PEOPLE - Specific programme "People" implementing the Seventh Framework Programme of the European Community for research, technological development and demonstration activities Grant agreement ID: 625915
Duration	16 June 2014 - 15 June 2016
Partners	HERIOT-WATT UNIVERSITY
Objective	Among the most prominent and ubiquitous anthropogenic changes in the marine environment has been the accumulation of plastic debris throughout the oceans. The physicochemical properties of plastics, extensive use in products and indiscriminate disposal are the key factors that contribute to the presence and abundance of plastics in marine environments. Larger pieces of plastic ultimately fragment into smaller particulates, and plastics are also manufactured as small particles or fibres that are eventually released into the environment. Small (< 5 mm) pieces of plastic (termed microplastics) have been reported in some coastal areas of Europe, but few areas have been evaluated and the extent of this environmental issue is unknown. Microplastics are ingested by organisms and the prominent concerns of this exposure include physical disruption of tissue surfaces, negative effects on digestive system processes, absorption across epithelial membranes and accumulation in internal tissues, trophic transfer in the food web and increasing the bioavailability of toxic substances (co-contaminants) that may be associated with microplastics. The goal of this project, MARMICROTOX, is to assess abundance and type of microplastics in wild mussels collected from sites on the coast of Scotland, as well as to conduct laboratory studies to investigate 1) accumulation, absorption, and negative effects of microplastics in mussels, 2) trophic transfer of microplastics and pathophysiology in fish and 3) effects of microplastics on co-contaminant bioavailability. These objectives will be met by testing the following specific hypotheses 1) the type of microplastic is related to accumulation, absorption and negative effects in organisms and 2) the physicochemical properties of both the microplastic and co-contaminant influence the effects of microplastics on co-contaminant bioavailability.
Main Results	Since plastics are non-biodegradable, they merely breakdown into smaller and smaller fragments with exposure to sunlight, wind and wave action. These fragments, known as microplastics (MPs), are only between 5 mm and 1 µm long and are reported to be the most abundant pieces of plastic found in marine ecosystems. They are also manufactured as small particles or fibres, which eventually find their way into the natural environment. The effect of MPs on marine organisms was investigated by the EU-funded project MARMICROTOX. This work assessed the extent and type of MPs found in wild mussels collected from sites around the coast of Scotland. Laboratory studies were also conducted to investigate the effects of MP uptake in the gills and digestive gland material of mussels and to assess the effect on fish. Results indicated that MPs were present in very low levels in wild mussels in Scotland and in mussels located in cages placed in the estuary of the river Forth, in Edinburgh, United Kingdom. The bioavailability to mussels of co-contaminants in the form of

	cadmium and benzo(a)pyrene sorbed onto MPs were only detected through digestion of high plastic particle concentrations. Studies of rainbow trout showed there were no overall indications of distress in fish exposed via ingestion to MPs or MPs with sorbed triclosan (a bactericide present in toiletry products), but that triclosan seemed to be bioavailable to the fish under study. MARMICROTOX represents an important step in the assessment and analysis of MP contamination levels and effects, leading to a clearer understanding of possible ecological risks.

Project title	W2PLASTICS: Magnetic Sorting and Ultrasound Sensor Technologies for Production of High Purity Secondary Polyolefins from Waste
Website	
Logo	
Programme	FP7-ENVIRONMENT - Specific Programme "Cooperation": Environment (including Climate Change) Grant agreement ID: 212782
Duration	1 November 2008 - 30 April 2013
Partners	- Technische Universiteit DELFT - Universita degli studi di Roma La Sapienza - Danmarks Tekniske Universitet - Universitatea Transilvania din Brasov - Barcelona Supercomputing center - Centro Nacional de Supercomputacion - Budapesti Muszaki es Gazdasagtudomanyi Egyetem - AKG Polymers B.V. - Bakker Magnetics BV - Recycling Avenue BV - Alcufer Ipari Kereskedelmi es Szolgaltato Korlatolt Felelossegu Tarsasag - S.C. Urban S.A. - OLDELFT BV - DV SRL - REDOX WASTE RECYCLING BV
Objective	The European consumption of plastics increased from 24,6 Mtons in 1993 to 39,7 Mtons in 2003 and its growth rate exceeds that of the economy as a whole. At the same time, polymer recyclers and manufacturing industries have a problem buying feed materials and secondary polymers of sufficient volume and quality, as a result of the pull of China and India on all raw material resources. The alternative of using more primary plastics has a range of environmental impacts and needs more resources (about two kg oil for one kg plastic). The polymer resources in complex wastes, such as WEEE, household waste and ASR (ACEA: 7.5 million tons of shredder residue in the EU17 in 2002), are largely unused, because of the problem to produce high-purity products from such sources at acceptable costs. Today just one million out of 14 million ton polyolefin's yearly sold in Europe is being recycled. W2Plastics aims to develop cost-effective and clean technology based on Magnetic Density Separation (MDS) and Ultrasound process control to recover high-purity polyolefins from complex wastes. A substantial effort is spent on making the new technologies fit in between the state-of-the-art technology of waste processors and the demands of the compounding and manufacturing industries by defining standards and best practices as well as effective quality-control tools (hyperspectral imaging). The integrated set of technologies and standards aims at changing the status of complex wastes to a resource of high-purity polyolefins for a wide range of industries. The development of

	such technology is in line with the European legislation (COM/2001/0031, 99/31/EC, 2000/53/EC, 2002/96/EC, 2003/108/EC) aiming at fostering the development environmental friendly technologies to reduce the environmental impact of human activities, to protect the environment, to minimize depletion of resources and to promote at the same time) business opportunities and improved competitiveness of European industry and SMEs.
Main Results	The techniques and technology used to separate and melt the plastics from demolition sites, for example, have yet to be honed for a viable solution. Producing high-purity polyolefin — a polymer used in a wide range of products — from such sites at acceptable costs remains elusive. With the support of EU funding, the W2PLASTICS project found a novel technique using innovative technology to separate the debris from the plastics. It developed a cost-effective and clean technology based on magnetic density separation (MDS) and ultrasound process control to recover high-purity polyolefins from complex wastes. The MDS was tested and able to recover more than 90 % of high-grade polymers from complex wastes. According to researchers, Europe currently only recycles 1 million out of 14 million tonnes of polyolefins sold annually throughout the EU. Researchers discovered that the compatibility of secondary polyolefins extracted from waste not only depends on quality but also on their melt flow index (MFI). Finding a constant MFI is vital and was listed as one of the most important criteria by plastic industry companies in a market analysis. The process is carried out by pouring complex waste into a liquid that is magnetised. Researchers developed a tool that both detects and controls the magnetised liquid. Certain debris then floats to the top. Ultrasound is used next to correctly identify polyolefin before it is extracted. Project researchers also developed a new quality control tool called hyperspectral imaging to retrieve polyolefins from complex wastes. It describes and quantitatively measures the incidence and types of polyolefins and contaminants inside plastic waste streams. The cutting-edge sorting technology introduced by W2PLASTICS offers a sustainable, long-term and low-cost alternative to producing secondary materials. The project outcomes will help decrease the negative environmental consequences of the plastic recycling industry, help replenish resources, and boost the competitiveness and job market in Europe.

Project title	CIRC-PACK: Towards circular economy in the plastic packaging value chain
Website	http://circpack.eu/
Logo	
Programme	H2020-CIRC-2016TwoStage Grant agreement ID: 730423
Duration	01 May 2017- 30 April 2020
Partners	- Fundación CIRCE Centro de Investigación de Recursos y Consumos Energéticos. - Fundación AITIIP. - NOVAMONT SPA. - MATER-BIOTECH SPA. - MATER-BIOPOLYMER SRL. - BUMAGA BV. - Nuevas Tecnologías para el Desarrollo del Packaging y Productos Agroalimentarios con Componente Plástica, S.L. - MI-PLAST DOO ZA PROIZVODNJU TRGOVINU I PRUZANJE USLUGA-MI-PLAST LLC MANUFACTURING, TRADING AND SERVICES MIPLAST. - Grupo SADA P. A. S.A. - SAPONIA KEMIJSKA, PREHRAMBENA I FARMACEUTSKA INDUSTRIA D.D. - Fater S.p.A. - Centro Ricerche FIAT SCPA. - Asociación Española de Normalización. - RINA Consulting SPA. - EKODENGE MUHENDISLIK MIMARLIK DANISMANLIK TICARET ANONIM SIRKETI. - Ecoembalajes España, S.A. - GRAD RIJEKA-GRADSKO VIJECE. - KARTAL BELEDIYE BASKANLIGI. - CALAF Tecniques Industrials S.L. - OCU Ediciones, S.A. - ICLEI European Secretariat GMBH. - PLASTIPOLIS.
Objective	It aims at more sustainable, efficient, competitive, less fossil fuel dependence, integrated and interconnected plastic packaging value chain. To this end, three case studies will work in developing, testing and validating better system-wide economic and environmental outcomes by i) decoupling the chain from fossil feedstocks, (ii) reducing the negative environmental impact of plastics packaging; and (iii) creating an effective after-use plastics economy. It will provide breakthrough biodegradable plastics using alternative biobased raw materials, which will have an instrumental role to play in the subsequence steps of the plastic value chain. In addition, eco-design packaging for improving and end-of-life multilayer and multicomponent packaging will be technologically advanced and adapted also to the new materials produced. Lastly, a multi-sectorial cascaded approach along plastic packaging value chain will be applied with critical impacts in other value chains beyond the targeted plastic packaging value chain to circular economy principles.

Main Results	- Result 1: New Biodegradable Bio-Based Polymers. Bio-based and biodegradable polymers obtained from 2nd generation feedstock and suitable for food and non-food packaging applications. - Result 2: THF Material (Tetrahydrofuran). Recovery of THF (separation and purification processes). THF has a great interest for potential market application, considering also the fact that is originated by a renewable feedstock. - Result 3: Intermediate layers of Degradable Materials in Multilayer Packaging. Intermediate layers of degradable materials into the packaging sector to foster degradation after some specific treatment or exposure time to certain conditions. - Result 4: Sorting Monitoring System. New process to asses the rheological and mechanical properties of the materials throughout the polymeric chain to ensure the quality of the material and its effective cost. - Result 5: Cellulose Material. FATER will obtain a high purity cellulose fraction which is of huge interest due to its purity degree for the subsequent bioconversion through enzymatic hydrolysis into fermentable sugars for the bio-based plastics production. - Result 6: Recycling Process of FATER. Circular process to re-use internally in the production of process of FATER the plastic fraction coming from the AHP waste treatment plant, decreasing raw material costs and increasing the environmental performance of its products. - Result 7: Recycling Process of MIPLAST. Re-use of internally plastic waste as a result of manufacturing and most important recycling of waste films and other plastic streams which comes from outside flows. - Result 8: Sorting Software. CALAF will develop the software and a full-scale testing equipment for the polymer detection and automated sorting of the materials. - Result 9: CIRC-PACK dynamic and interactive virtual map. CIRCE will develop a map based on the evaluation of an innovative set of indicators able to provide a holistic perspective for future implementation of CIRCK-PACK innovations, maximizing the replicability of the project.