MARINE LITTER: HOW TO MONITOR, REDUCE AND PREVENT OCEAN DEBRIS

Focus on plastics and microplastics
Preface

The global production of plastics is continuously increasing and millions of tons of plastic waste have found their way to the oceans. It is everywhere, from the sea surface to the sea floor, from the Arctic to the Antarctic, from remote islands to our rivers shores. Microplastics in particular are found in a large variety of marine organisms, including in species we consume as seafood.

Knowledge of the sources, fate and impact of plastics in the marine environment is far from complete, but what is known is worrying. This has serious environmental, social and economic consequences. In addition to harming the environment, marine litter damages activities such as tourism, fisheries and shipping.

Due to the plastic persistency, these impacts are growing as each year we generate more plastic waste. The magnitude of the seas and oceans (combined surface of 350 million km² and a volume of 1,300 million km³) makes the removal of plastic litter an immense challenge.

At the same time, valuable material that could be brought back into the economy is lost, once littered. The potential economic and environmental benefits of a more resource-efficient and circular approach are not realized. The need to tackle these problems and reduce the environmental, economic and social harm is widely recognized.

Although our knowledge is still fragmented, what we already know shows we should not wait before taking action. This action should focus on where it is the most effective taking into account several environmental, economic and social parameters, as well as fully exploiting available technologies and developing new ones even more effective.

Efforts to fight the plastic pollution are being made. Initiatives are taken at local, national, European and worldwide level, at both short term and long term. Social awareness is increasing.

Plastic has become an important and necessary part of our daily life. However, its negative consequences when ending up in the environment can no longer be ignored. There is a need to get smarter about plastic, adopting a more circular economic model.
Abstract

We live in the age of plastics. They are ubiquitous in our daily life and in many industrial applications. They play a major role in our economy. Their production continuously increases. However, plastics are not well managed and found their way to the oceans, leading to far-reaching environmental, health, social and economic impacts. Hence the challenge is to maintain the economic and societal benefits brought by plastics but avoiding that they end up in the environment.

Although there are knowledge gaps, the key elements are clear: 80% of marine litter is plastics. 94% is on the sea floor, only 1% is floating. Half of the marine litter are single use plastics. Marine plastic litter is found in high concentration on beaches, two orders of magnitude higher than anywhere else. The key points of intervention are beaches, wastewater treatment plants, and rivers. Floating plastics might therefore be less important than it can appear in the media.

Many efforts are being implemented at all levels, local, national, European, G7 and worldwide. However, plastics remain overall wrongly managed, in particular in Asia (China and South East Asia). Social awareness is increasing but so do the plastic ending into oceans. There is no one magic bullet solve-it-all solution. What counts most is the coherence between different solution to form a strong package of measures.

SWOT analysis of 4 main categories of measures (i) plastic removal, (ii) transformation/recycling, (iii) WWTP (Waste Water Treatment Plant), and (iv) monitoring, and 31 corresponding technologies were reviewed with their TRL (Technology Readiness Level) estimated.

Outcome indicates that the preferred solution in each category is: (i) beach clean-up as it is easy access, highly concentrated and shows strong economic benefits, (ii) Membrane technology appears to be the best technology for filtering microplastics (MPs) and this can be operated in a key intervention point (WWTPs), (iii) monitoring is necessary for informed policies but likely to be difficult and expensive. The FerryBox system appears the most promising but monitoring from space might be the technology that can bring a paradigm change as it did some years ago to measure plankton, and (iv) regarding transforming and recycling the tailor-made solution of Dutch start up “The Plastic Mining Cooperation” that develops for plastic waste on islands and coastal areas appears to be the “best” one, also cooperating with local environmental organizations and waste management companies they aim at turning waste into a resource.

Overall, three main conclusions emerged from the research project (i) Prevention is better than cure. There is still no solution found for the 94% of plastics on the sea floor, (ii) one size does not fit all. Technologies should be adapted to the social and industrial context of the point of intervention, and (iii) there is a need to develop at the same time long term and short-term approaches. It will be a long journey, but it starts now.
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Introduction

Plastics are ubiquitous in our daily life and in many industrial applications. The growing abundance of plastics in our environment is such that the Anthropocene can be characterized by its presence in strata almost globally, reaching even the most remote parts of the world such as the deep-sea floor and the polar regions (Zalasiewicz et al., 2016).

Plastics are ubiquitous for good reason, they play a major role in our economy. Suddenly stopping their use is unlikely to be feasible nor desirable. Plastics’ longevity in the environment as well as its low rate of recycling makes it a problem on the global level. Its accumulation in the environment and most notably in the marine environment is leading to far-reaching environmental, health, social and economic impacts. Indeed, this pollution is damaging our ecosystems and our economies (Löhr et al. 2017).

Marine litter, and especially plastic, has been the subject of increasing concerns at a global level due to the increasing amount of plastic released into the oceans each year. It is estimated that, for the year of 2010 alone, approximately 4.8 to 12.7 million metric tons (MT) of plastic entered the ocean (Jambeck et al. 2015).

Approximately half of all marine litter is made up of single use plastics (Eunomia, 2016; EU Commission, 2018). This is due to the fact that most of all plastics are used for packaging and also because of the global shift from reusable containers and items to single-use containers and items, such as cotton-buds, plastic bottles, etc. (Geyer et al., 2017). These plastics are in general intended to be used for less than a year (Ellen MacArthur Foundation, 2016; Geyer et al., 2017) but when released in the marine environment, they can persist for a much longer time.

Even if plastics are durable materials, they are slowly degraded in the environment via photo-oxidation, thermo-oxidation, and mechanical degradation (e.g. waves, sand). The rate of degradation depends on the chemical nature of plastics, and the environmental conditions (e.g. temperature, sunlight and oxygen levels) (Andrady, 2015; Andrady, 2011). Oxidation breaks chemical bonds of long chain molecules, making them fragile and leading to smaller fragments and therefore forming microplastics (MPs) (Cooper and Corcoran, 2010). Abiotic factors are not the only cause of fragmentation of plastic litter, biological processes are also capable of forming MPs (Kühn et al., 2015). MPs are usually defined as being less than 5mm in size.

The amount of marine plastic litter is growing as each year we generate more plastic waste. And it is very difficult (if not impossible) to remove all the marine litter as the seas and oceans have a combined surface of 350 million km² and a volume of 1300 million km³.

Population size and waste management systems play an important role in determining the quantity of plastics that are released into the oceans for a particular country. The most polluting countries with regards to releasing plastic debris in the oceans are located in southeast Asia, the top five being China, Indonesia, Philippines, Vietnam, and Sri Lanka (Jambeck et al. 2015).

Plastic marine litter has been estimated to cost US$1.26bn per annum in 2008 terms to marine industries of the 21 economies of the Asia-Pacific Economic Cooperation (APEC) (McIlgorm et al. 2011). However, the research regarding the valuation of the damages caused by plastic debris and the possible methods to mitigate these damages is still hindered by the lack of knowledge on this problematic.

The current approach to producing, using, managing and disposing of plastics poses a significant threat to the environment, to livelihoods and potentially to human health. It also represents a significant loss of value, resources and energy. The need to tackle these problems and reduce the environmental, economic and social harm is widely recognized.
Hence the challenge is to maintain the economic and societal benefits brought by plastics but avoiding that they end up in the environment. At the same time, valuable material can be brought back into the economy if plastics are recycled. The potential economic and environmental benefits of a more resource-efficient and circular approach can be realized.

Recently, a Horizon 2020 EU research project called “Cleaning Marine Litter by Developing and Applying Innovative Methods” (CLAIM) has been funded with not only the goal to study the presence and effect of marine litter (and especially plastic) but also to develop new ways to remove it from the oceans. CLAIM is developing new technologies that have different aims which can be separated in four categories: monitoring, litter removal (clean-up), litter transformation (e.g. recycling), and wastewater treatment plants.

In this paper, already existing or in development technologies will be analyzed with a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) in order to measure and quantify the efforts put into solving the global problem that plastic marine litter represents.

Hence, this paper will aim to answer the following questions:

- Where does marine plastic waste come from, where does it go, and what is its impact?
- What are the existing (and being developed) efforts, actions and technologies to reduce plastic marine litter?
- Which are the preferred technologies given their estimated Technology Readiness Level and their potential environment, economic and social impact? Are the efforts put in the right place (key intervention points)? And do they have the right balance between cure and prevention?
I. Theoretical Framework

1. Plastic production and uses

We live in the age of plastic: 335 million metric tons (MT) of plastic were produced globally in 2016 (PlasticsEurope, 2017). Figure 1 shows the production of plastic from 1950 to 2016 in million MT.

![Global Plastic production from 1950 to 2016](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAAAEAAAABBQcAAAAACn2A4AAAAAElFTkSuQmCC)

*Figure 1: Global plastic production from 1950 to 2016, in millions of metric tons (MT) (data of plastic production from PlasticsEurope, 2015 & PlasticsEurope 2017).*

Global plastic production has significantly increased since the 1950s: from 1.5 million of tons produced to 335 million of tons produced in 2016 (Figure 1). It is estimated that a total of 8300 million MT of plastic has been produced since the 1950’s (Geyer et al., 2017). Plastics are made almost entirely from fossil feedstocks such as oil, coal, or natural gas. This represents only a fraction (4-6%) of all the oil and gas used in Europe for example because the vast majority is used for either transport, electricity, or heating (PlasticsEurope, 2017). Only a very limited amount of plastic is biodegradable plastic and do not originate from fossil fuels, accounting for only 4 MT globally (Geyer et al., 2017).

There is a large diversity of plastics divided between the thermosets and the thermoplastics. Thermoplastics can be reshaped as many times as desired by melting and cooling, but that is not the case for thermosets. When heated, thermosets undergo chemical changes which prevent them from being re-melted and reformed.

Thermoplastics include: Polyethylene Terephthalate (PET), Polypropylene (PP), Polystyrene (PS), Polyethylene (PE), Expanded polystyrene (PS-E), Poly methyl methacrylate (PMMA), Polycarbonate (PC), Polyamides (PA), Thermoplastic elastomers (TPE), Fluoropolymers Polyarylsulfone (PSU), etc.

Thermosets include: polyurethane (PUR) epoxy resins, unsaturated polyester, acrylic resins, vinyl ester, urea – formaldehyde, phenol – formaldehyde, vinyl ester, phenolic resins, silicone, melamine resin, etc.

The large variety of plastics reflect the many different uses that we have for plastics.
Plastics are omnipresent in our daily life because so many items that we use every day are made of plastic. Indeed, plastics are an important part of our economy, for example, by providing direct employment to 1.5 million people in Europe (PlasticsEurope, 2017). Most of the plastic in the world is produced in Asia, as is clearly visible on figure 2, with China being the biggest plastic producer in the world (29%). However, when looking at figure 3, it becomes evident that the biggest plastic users are the industrial countries such as the USA, Canada, Mexico, Western Europe, and Japan. These countries use 2 to 3 times more plastic than the rest of Asia for example.

![Figure 2: World repartition of plastic production in 2016. Plastic materials: only thermoplastics and polyurethanes (PlasticsEurope, 2017).](image)

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![Figure 3: Plastic use repartition across the world (Grün, 2016; PlasticsEurope, 2015).](image)

Figure 3: Plastic use repartition across the world (Grün, 2016; PlasticsEurope, 2015).
While plastics have many uses, one of them is dominant over the others by far. Packaging represents almost 40% of the plastic used in Europe (figure 4).

Not only are single use plastics (SUPs) the most fabricated type of plastics, they are also the shortest-lived (because most of them are used for packaging purposes) (see figure 5). Although SUPs are only used for a short time (approximately 1 year), because they are made of non-biodegradable matter, they are able to persist for a long time in the environment. As a result, plastic waste accumulates (if it is not burned or recycled) in landfills or in the natural environment (Barnes et al., 2009). It is estimated that 30% of all plastic ever produced (2500 MT) is currently in use (Geyer et al., 2017).

Figure 4: Plastic use by sector in Europe in 2016 (PlasticsEurope, 2017)

Figure 5: Product lifetime distributions for the eight industrial use sectors plotted as log-normal probability distribution functions (PDF) (Geyer et al., 2017)

2. Plastic waste management around the globe

Plastic waste management is a cause of increasing concern because of the notorious longevity of plastics in the marine environment and also because of their harmful effects on the environment, and potentially on humans (Thompson et al., 2009). Geyer et al. estimated that as of 2015, 6300 MT of plastic waste had been generated, of which 9% was recycled, 12% was incinerated, and 79% was accumulated in land-fills or the natural environment.
Plastic marine litter can be found everywhere in the oceans from the sea floor to the arctic sea ice as well as on the coasts and floating in the open seas (Obbard et al., 2014; Barnes et al., 2009). There are different pathways for plastics to enter the oceans. The main pathway is land-based coastal pollution which accounts for approximately 80% (Eunomia, 2016) of the plastics released in the oceans and representing an estimated 9 million MT (mid-point estimate) (Jambeck et al. 2015). Another important pathway is plastic directly released at sea which accounts for 1.75 million MT per annum (Eunomia, 2016) and is composed at 65% of lost or discarded fishing gear and 35% from shipping sources (Arcadis, 2012). Finally, another pathway is plastic coming from inland and is usually carried by rivers. This pathway accounts for 0.5 million MT per annum (Eunomia, 2016).

The main drivers behind this plastic pollution are population size and the quality of the waste management infrastructure/systems in place. The importance of plastic waste management is highlighted by the fact that “without waste management infrastructure improvements, the cumulative quantity of plastic waste available to enter the ocean from land is predicted to increase by an order of magnitude by 2025” (Jambeck et al. 2015).

Figure 6: Global estimated mass of mismanaged plastic waste in millions of metric tons (MT) generated in 2010 by populations living within 50 km of the coast (Jambeck et al. 2015). Detailed data available in Appendix 1.

Figure 6 provides a global overview of plastic waste management for 192 countries (countries in white not included). It is interesting to note that 93% of the global population live within 50 km of the coast. In this study by Jambeck et al. they defined mismanaged waste as follows: “[…] material that is either littered or inadequately disposed. Inadequately disposed waste is not formally managed and includes disposal in dumps or open, uncontrolled landfills, where it is not fully contained”.

There are many factors influencing the composition of waste: the level of economic development, climate, energy sources, etc. As countries becomes wealthier, the proportion of plastic waste tends to increase as well (appendix 2). As a result, over the last decades there has been an increase in the proportion of plastic waste: from less than 1% of the total municipal solid waste (MSW) in 1960 (in the United States) to 12 % in 2010 (EPA, 2010). This increase is not limited to the U.S. and has been observed globally. Nowadays, plastic waste makes up roughly 10% of solid waste by mass for a majority of countries (Hoornweg & Bhada-Tata, 2012). Appendix 3 shows the global solid waste composition.

In order to deal with MSW, the most common methods are landfilling and thermal treatment. Although the treatment of MSW is also highly dependent on how developed a country is. Looking at the example of Europe, figure 7 shows that the landfilling rates of plastic waste are very uneven across Europe.
General trends are visible on this figure: countries in the North seem to be doing better than countries in the South (notably due to landfill restrictions put in place) and countries in the East seem to be doing worse than countries in the West.

Figure 7: Plastic landfilling rates across Europe (PlasticsEurope, 2017)

Figure 8 shows that where landfill restrictions are in place, there is indeed very little to no landfilling at all, and also that the landfilling has been replaced by energy recovery instead (thermal treatment). All European countries show recycling rates of 20 to 40% for their plastic waste.

Figure 8: Plastic post-consumer waste rates of recycling, energy recovery and landfill per country in 2016 (PlasticsEurope, 2017)

It is worth mentioning that packaging plastics are recycled more often and in larger proportions than other plastics. Indeed, these SUPs are recycled at a rate of 40.8% on average in Europe when the requested level is 22.5% by the EU Packaging Waste Directive (PlasticsEurope, 2017; European Council EC Packaging Waste Directive, 1994).

Plastic packaging waste accounted for 16.7 million MT and representing 62% of the total 27.1 million MT of plastic waste collected in 2016 in Europe. This packaging plastic was recycled at the high rate of 40.8% (higher than any other type of plastic), 20.3% was landfilled, and 38.8% went into energy...
recovery (average value for the 28 member states combined) (PlasticsEurope, 2017). However, recycling merely delays “final disposal” rather than bypass it completely (Geyer et al., 2017). In order to reduce primary plastic production, recycling needs to actually result in a displacement of primary plastic production (Geyer et al., 2016), but that displacement is overly challenging to establish (Zink et al., 2017).

As a general guideline the preferred options for dealing with waste are shown on figure 9.

![Figure 9: Most and least preferred options for dealing with waste (Hoornweg & Bhada-Tata, 2012. Appendix 11 provides more information about waste disposal options.]

Furthermore, populations and waste generation will continue to rise for the foreseeable future, especially in developing African countries and urban areas (Jambeck et al., 2015). As a country becomes more developed, the amount of waste it produces reaches a limit. As the world is developing, global MSW will peak, but this peak is not predicted to happen before 2100 (Hoornweg et al., 2013).

Because of the increase of plastics as part of our waste, landfilling and incinerating our waste will not be sufficient in the future. More sustainable solutions will have to be found such as reducing waste generation but also developing waste management infrastructures, especially in developing countries.

Such investments will be costly and will take time, in the meantime reducing the use of single-use plastics should be the priority for industrialized countries.
3. Environmental and Economic impact of marine litter

a. Where is marine plastic litter located?

On a global scale several studies have estimated the amount of plastic present in our environment. Figure 10 shows the total quantifiable amount of plastic on the sea floor, floating, or on the beaches. Figure 11 represents the different concentrations of plastic marine litter floating in the oceans, lying on the sea floor, or littering our beaches. Figure 12 shows the composition of marine litter and that it is indeed mostly plastic made of plastics.

When looking at these figures it becomes evident that the large majority of plastics in the oceans are located on the sea floor (94%). This represents an estimated 25.3 to 65 million MT of plastic marine litter (Pham et al., 2014). There’s also only an estimated 1% of plastic floating in the oceans despite the high-profile projects that aim to clean these up by removing them from the open oceans. Floating plastics represent an estimated 0.27 million MT (Eriksen et al., 2014; Cózar et al., 2014; The Ocean Conservancy, 2012; Ryan et al., 2014; Smith et al., 2013; Kusui and Noda, 2003; Pham et al., 2014).

Floating plastics have a very low concentration of 18kg/km² but this is only in the spot with the highest concentration recorded (the North Pacific Gyre), the average concentration is roughly estimated to be much lower, at 0.74kg/km² (including microplastics). The beaches present an interesting case, while only accounting for 5% of the total plastic in the marine environment, it is present with an elevated concentration of 2000 kg/km², representing an estimated 1.4 million MT (The Ocean Conservancy, 2012; Ryan et al., 2014; Smith et al., 2013; Kusui and Noda, 2003; Pham et al., 2014). This information is summarized in the form of an infographic in appendix 4.

b. Environmental Impact

The impacts of plastic marine litter include: ingestion, entanglement, “ghost fishing”, release of toxic substances (chemical additives present in plastic) which can themselves have an impact, and finally it can act as a vector for the transportation of invasive species. Furthermore, marine litter threatens not only species and ecosystems, but human welfare and human health as well. The two main impacts remain ingestion and entanglement (Werner et al., 2016). Both of these can lead to a reduction in the
ability to capture and digest food, sense hunger, but also it can impede locomotion making it harder to escape from predators, jeopardizing the ability to migrate and reproduce (CBD, 2012). The ingestion of plastics, and in particular MPs, provides a pathway for toxic chemical compounds to enter the food chain. Because MPs are smaller (less than 5mm), they can be ingested by smaller biota, which form the base of the food chain. Toxic compounds such as phthalates and Bisphenol-A (BPA) are commonly found in plastics and negatively affect reproduction and cause genetic mutations (Oehlmann et al., 2009). The impact is negative; however, it is not properly quantified, it remains uncertain the extent to which chemicals from plastic marine litter play a role in affecting biota in its natural environment (Werner et al., 2016).

Many species are affected by marine litter, as reported by the Secretariat of Convention on Biological Diversity (CBD). A total of 817 species are impacted (CBD, 2016), which represents a 23% increase compared to the previous report of 2012. If only taking into account the two most important impacts (ingestion & entanglement), a total of 519 species are impacted (CBD, 2016). In areas of higher concentration of plastic, such as oceanic gyres, some species are particularly impacted like the planktonic invertebrates (CBD, 2016).

c. Economic impact

Marine litter represents a risk not only to the environment and biota, but also to ecosystem services and human welfare. Certain sectors such as tourism, fisheries, and navigation are negatively impacted by marine litter and results in an economic loss (Werner et al., 2016). Because of the nature of marine litter, its point of origin can be very far from the impacted area, placing a burden on economies that are not necessarily responsible for the pollution. The United Nation Environment Protection (UNEP) estimated the total natural cost to marine ecosystems of plastic littering at USD 13 billion per annum (UNEP, 2014). However, due to limited and fragmented information about the impacts marine litter has on the environment and on human welfare, it is complicated (if not impossible) to compare the costs of measures preventing marine litter with the costs incurred by remediation (Brouwer et al., 2015). Despite these constraints, there are more and more research on the negative externalities caused by marine litter (e.g. Watkins et al., 2016). The impacts of marine litter are summarized in the form of a logical impact diagram in figure 13.

![Logical Diagram of impact](image-url)

*Figure 13: “Logical Diagram of impact” for beach and marine litter on socio-economic activities (Mouat et al., 2010; McIlgorm et al., 2011; Reinhard et al., 2012)*
In order to achieve the transition to a more circular economy, tackling the marine litter problem will play an important role. Indeed, plastic is a valuable resource and all this plastic marine litter represents an opportunity to increase efficiency, to reduce marine litter, and to better use our plastics (Watkins et al., 2016). The economic impacts on the most affected sectors are summarized below in figure 14.

<table>
<thead>
<tr>
<th>Fisheries and aquaculture</th>
<th>Cost</th>
</tr>
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<tbody>
<tr>
<td>Removal of plastic litter from the fishing nets</td>
<td>At the European level, Acoleyen et al. (2013) estimated that the costs due to damage and losses reaches approximately €61.7 million, equivalent to a reduction of nearly 1% of the total revenue generated by the EU fleet in 2010. Werner et al. (2016) put the level at 5 %.</td>
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<tr>
<td>Reduction of catches</td>
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<td>Repairing damaged fishing gear</td>
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<th>Shipping and ports</th>
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<td>Blockages of ship propellers, anchors, intake pipes and valves</td>
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<td>Damaged boats</td>
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<th>Clean-up activities</th>
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<tr>
<td>Clean-ups of floating marine litter or litter deposited on the sea-floor</td>
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<td>Fishing for litter operations</td>
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<th>Coastal communities and tourism</th>
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<td>Keeping beaches clear of litter</td>
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<th>Long term impacts</th>
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<tr>
<td>Damage to economic activities</td>
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<tr>
<td>Long-term accumulation of material in all levels of the food chain</td>
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</table>

Figure 14: summary of economic impacts of marine litter (Werner et al., 2016; Acoleyen et al. 2013). More detailed information of the cost of fisheries can be found in appendix 12.

4. Governmental actions

Different governmental actions were developed since the end of the past century, especially in developed countries. Many countries are taking actions to reduce marine plastic pollution but the situation varies for every country, as seen in the example of the different landfilling rates of plastic litter across Europe (figure 7). Numerous other examples include: the single-use plastic bags are banned from stores since 1st January 2016 in France; in Switzerland, individuals pay a tax based on the amount of waste produced according to the “polluter-pays” principle; in Belgium, recycling bins have been made mandatory. Many more actions have been undertaken to tackle the plastic problem. Several European countries are taking action against single use plastic. For example, France has banned plastic cups and plates, Italy and France are banning plastic cotton buds, the UK wants to ban straws, joined by the Brussels region
recently, and other countries like Ireland and Portugal are considering measures. All these measures are intended to reduce the amount of plastic waste generated.

For the year 2016, Europeans generated 27.1 million MT of plastic waste, of which 31.1% was recycled, 41.6% was incinerated (with energy recovery) and 27.3% was landfilled (PlasticsEurope, 2017). At the level of the European Union and its 28 Member States, a strategy on plastics was adopted in January 2018 (EU commission, 2018) as a part of the transition towards a more circular economy. This strategy highlights that protecting the environment from plastics is beneficial to businesses in transforming the way plastic products are produced and recycled, and it will also boost innovation and investment. The EU strategy includes in particular:

- Making recycling profitable for business: new rules on packaging will be established to improve the recyclability of plastics
- Curb plastic waste: focus on single-use plastics and fishing gear, measures to restrict the use of MPs in products, and fix labels for biodegradable and compostable plastics.
- Stop littering at sea: new rules on port reception facilities will tackle sea-based marine litter

In addition, the European Commission proposed in May 2018 new EU-wide rules to reduce marine litter (EU commission, 2018). The main targets are the 10 most often found SUPs (see figure 15) on Europe's beaches and seas, as well as lost and abandoned fishing gear. Together these plastics constitute 70% of all marine litter items (Werner et al., 2016; Eunomia, 2016; EU Commission, 2018).

The new rules include in particular:

- A plastic ban on certain products where alternatives are readily available, and a ban on affordable single-use plastic products. The ban will apply to plastic cotton buds, cutlery, plates, straws, drink stirrers and sticks for balloons which will all have to be made exclusively from more sustainable materials instead.

- Single-use drinks containers made with plastic will only be allowed on the market if their caps and lids remain attached.

![Figure 15: Tackling the 10 most found SUPs on European beaches (EU commission, 2018)](image-url)
Plastics producers will help cover the costs of waste management and clean-up, as well as awareness raising measures. The Commission's proposals will now go to the European Parliament and Council for adoption.

At G7 level, the leaders of Canada, France, Germany, Italy, the United Kingdom, and the European Union agreed at the G7 meeting in Canada on the 10th June 2018 on an Ocean Plastics Charter to move toward a more resource-efficient and sustainable approach in the management of plastics. They decided to take action toward a resource-efficient lifecycle management approach to plastics in the economy by:

- Sustainable design, production and after-use markets, in particular working with industry towards 100% reusable, recyclable plastics by 2030, and reducing the use of plastic microbeads in rinse-off cosmetic and personal care consumer products.

- Collection, management and other systems and infrastructure, in particular working with industry to recycle and reuse at least 55% of plastic packaging by 2030, accelerating international action and catalyzing investments to address marine litter in global hot spots capacity development for waste and wastewater management infrastructure.

- Sustainable lifestyles and education, in particular to support platforms for information sharing to foster awareness and education efforts on preventing and reducing plastic waste generation, plastics pollution and eliminating marine litter.

- Research, innovation and new technologies, in particular (i) promoting the research, development and use of technologies to remove plastics and MPs from waste water and sewage sludge, (ii) guiding the development and appropriate use of new innovative plastic materials and alternatives to ensure they are not harmful to the environment, and (iii) research on the sources and fate of plastics and their impact on human and marine health.

- Coastal and shoreline action, in particular encouraging campaigns on marine litter with youth to raise public awareness, collect data and remove debris from coasts and shorelines globally.

At a worldwide level, the United Nations Environment Programme (UNEP) has “declared war on plastics”. In 2017, it launched a global campaign to eliminate major sources of marine litter: MPs in cosmetics and the excessive usage of SUP by the year 2022 (UNEP, 2016). Countries in the world have joined the campaign with pledges to reduce plastic pollution. For example, Indonesia has committed to reduce its marine litter by a 70 per cent by 2025; Uruguay will tax single-use plastic bags later this year and Costa Rica will take measures to reduce single-use plastic through better waste management and education.

As shown on figure 16, six regional action plans for marine litter are being developed by UNEP.
The following regions are concerned:
- Regional Plan on the Management of Marine litter in the Mediterranean
- Convention for the Protection of the Marine Environment of the Northeast Atlantic.
- Action Plan on Marine Litter for the Wider Caribbean Region
- Northwest Pacific Action Plan on Marine Litter
- South Pacific: Pacific Regional Waste and Pollution Management

In all the above mentioned governmental actions, the question of social awareness and public perception appears crucial. Information campaign are organized, e.g. CREA’s video on marine plastic litter went viral and gathered millions of views around the world (original video available at https://www.youtube.com/watch?v=2_gUollvZxQ, the video that went viral is an edit of this original version).

Awareness raising campaigns underline the need for simple steps to be implemented by individuals in their daily lives such as using their own reusable drink bottles or coffee cups, purchasing a long-life reusable drink bottle, steering clear of products with microbeads, participating in a clean-up operation, etc. NGOs also encourage people to stimulate local politician to do the same. This illustrates well the tandem approach of several NGOs, with need to make the change in our own lives, and also demand that government supports people in doing so by implementing appropriate bans and legislation.

Nationwide there are heaps of groups running exceptional education programs for school kids. They’re bringing the message to schools and helping the next generation plan how to stop plastic from making it into the ocean.

“In 2050 there will be more plastic in the oceans than fish” is for example a strong slogan (World Economic Forum, 2016). Video campaigns, shocking images of sea life destructed, strong reactions of well-known personalities (divers, actors, writers, politicians).
II. Research Methodology

In order to quantify the efforts that are put in combating plastic marine litter globally, it will require to have an overview of the existing and developing technologies that are used to do so. Finding and identifying these numerous technologies can be done via a literature review, searching on the internet, etc. All these technologies can then be aggregated into a table summarizing the most important information such as the Technology Readiness Level (TRL), costs, environmental, economic, and social impacts. In this table the technologies are also organized within four different categories: monitoring technologies, wastewater treatment technologies, litter collection technologies, and litter transformation technologies. Monitoring technologies aim to provide accurate data informing us on the quantity, characteristics, behavior, etc., of marine litter. Wastewater treatment technologies are mostly concerned with filtering MPs in wastewater treatment plants (WWTPs). Litter collection technologies involve the removal or capture of plastic litter (clean-up). And finally, litter transformation technologies involve reprocessing plastic into something useful such as energy (via a thermal treatment for example) or into another material.

1. Different methods: CBA, MCA, CEA, Delphi and SWOT

To review this information methodologically, several options are available:

A Cost-Benefit Analysis (CBA) consists of putting in monetary terms the costs and benefits. This step is of critical importance and is also where the difficulty lies in conducting a CBA. Indeed, putting into monetary terms non-monetary costs and benefits can be challenging and will require assumptions to be made. Another shortcoming of this method is that it may ignore the distributional effects (or accommodates poorly for it), the winners and losers are not visible with an overall net benefit for example. Some parameters also require some amount of subjectivity such as selecting the discount rate. The main advantage of this methodology is that it provides an objective unit of measurement (monetized value) which can easily be used to compare alternatives, maximizing the net total benefits. A typical methodology for conducting a CBA is represented in Appendix 5.

Multi-Criteria Analysis (MCA) is another well-established decision-making tool that can be used to compare different alternatives. MCA involves selecting the best alternative based on the objectives set previously (criteria). This method is often selected because it is more flexible than a CBA and can better deal with non-monetary values. Indeed, where in a CBA there’s a need for monetary terms in order to conduct the analysis whereas in MCA the criteria do not need to be quantified in monetary term. The criteria are aggregated to provide a score for the overall performance of each alternative which allows to rank the alternatives and inform decision-making. The steps to be taken in MCA are represented in appendix 6.

A Cost-Effectiveness Analysis (CEA) is closely related to a CBA. However, instead of necessarily using monetary terms to quantify the benefits, a CEA only aims at quantifying the benefits (not monetize them necessarily). The benefit-cost ratio is calculated which gives an indication on the “value of money”. This method can answer questions such as: “how much litter (kg) can be removed from the oceans for 1€?”. The steps to be taken in a CEA are represented in appendix 7.

The Delphi method relies on a panel of experts. It is an organized communication method which involves several rounds. During each round the experts answer questionnaires. These questionnaires are then summarized and shared amongst the experts. In light of the other experts’ opinions and knowledge,
the second round begins. The range of answers should then converge towards a consensus between the experts. The steps to be taken in the Delphi method are represented in appendix 8.

The Strengths, Weakness, Opportunities, Threats (SWOT) analysis examines (like its name suggests) the strengths and weaknesses (internal) as well as the threats and opportunities (external) for a project or a business. This method can be used for any situation requiring strategic planning to reach an objective. Strength and Weakness represent the internal factors over which there is control. Threats and Opportunities represent the external factors over which there is no control. The analysis determines whether these internal and external factors may support or hinder the objective. The SWOT analysis can lead to a strategy or an action plan for dealing with negative factors while maximizing strengths and opportunities. It is common to represent a SWOT analysis in a 2x2 matrix putting the categories side-by-side, making it easier to see correlations among them. It is effective for analyzing and creating a simplified picture of a complex situation.

To properly conduct the analysis of the efforts put into combating plastic marine litter, the CBA and MCA would have been the first and second choice respectively however, this was not possible due to a lack of data as well as a lack of time available. In this context, the SWOT analysis appears therefore as an appropriate method to identify and understand key issues in a complex situation with limited time and data available. Another advantage of the SWOT analysis is its flexibility and that it focuses on the most important factors to address weaknesses, deter threat, capitalize on opportunities, take advantage of the strengths.

However, SWOT analysis is only one step which needs more in-depth research and analysis to make decisions. It is difficult to address uncertain or two-sided factors such as factors that could be both a strength and a weakness with a SWOT analysis.

2. Technology Readiness Level

One of the main measurements to determine how much effort is put into which technology is the TRL of each technology. In addition to other information regarding costs and impacts, the TRL represents the main “measuring stick” to quantify the effort.

Technology Readiness Level scale was originally conceived at the National Aeronautics and Space Administration (NASA) during the 1970-80’s and has since disseminated in many different sectors while being adapted to their characteristics (EARTO, 2014). TRL is a method of estimating technology maturity on a scale from 1 to 9, with 9 being the most mature technology. TRL was initially defined as follows: “a discipline-independent, program figure of merit (FOM) to allow more effective assessment of, and communication regarding the maturity of new technologies” (Mankins, 2009). The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology (EARTO, 2014). The following (figure 17) briefly describes each level. More detailed definitions can
be found in the appendix 9. These are the definitions used within the Horizon 2020 program as well as the definitions by Mankins.

![Assessing Specific Technology “Functional Maturity”](image)

Figure 17: Technology Readiness Levels (Mankins, 2009)

Technology readiness levels are often grouped; for example, the OECD distinguishes 4 research levels: Basic research (TRL 1-3), Development (TRL 4-5), Demonstration (TRL 6-7), and Early deployment (TRL 8-9) (Ekins & Salmons, 2010). A more detailed description of the OECD categories can be found in the appendix 10.

The limitations of the use of TRLs approach includes the (i) lack of attention to setbacks in technology maturity (an increase in maturity also requires additional research), (ii) single technology approach (TRL is not adapted to evaluate complex systems combining different technologies although it is often the case in real life), (iii) Focus on product development, rather than manufacturability, commercialization and organizational changes (for example, the readiness of an organization to implement the innovation, are not incorporated).

3. The four categories

This section provides a description for the four categories used to differentiate the different technologies.

a. Wastewater treatment plants technologies

These technologies are mostly concerned with filtering MPs in WWTPs. Indeed, WWTPs are a significant point source of MPs pollution. Even though conventional WWTPs with a primary and secondary treatment are efficient in their removal of MPs (up to 99%) (Carr et al., 2016; Murphy et al., 2016; Tavilitie et al., 2017), WWTPs can still act as an entry point to the environment for MPs due to the large amounts of effluents (Mason et al., 2016; Murphy et al., 2016; Mintenig et al., 2017; Tavilitie et al., 2017). Currently, the majority of WWTPs are not outfitted to filter MPs specifically.
b. Monitoring plastic marine litter technologies

Monitoring technologies are mostly concerned with means of detecting and quantifying the presence of plastic marine litter. Monitoring marine litter provides essential information which help decision makers make informed decisions in order to address the problem efficiently. There remain currently significant data gaps concerning marine litter despite the growing research. Monitoring can help establish the location and quantity of marine litter, and better understand it in order to better manage it.

The biggest problem with getting good data is the massively varying abundance of litter depending on when and where you measure. Litter moves between beaches, within the water column, and the sea bed depending on the season and the weather. In order to identify trends in such ‘noisy’ data, a significant number of data points, spread out in time and location, are required. Statistical analysis suggests that, in order to detect a 50% increase in microplastic litter floating in the Northeast Pacific with 80% probability would require 250 samples. Monitoring on this scale is likely to be difficult and expensive (Eunomia, 2016).

Conducting manual observations and the sampling tools necessary in order to so are both costly and time-consuming. Moreover, these can sometimes be influenced by the operators (Kako et al., 2014). In order to identify properly the different types, sources, temporal trends, and potential pathways of marine debris, new monitoring tools are required (Criddle et al., 2009; Gregory et al., 2009; Ribic et al., 2010).

c. Plastic litter transformation technologies (recycling)

Transformation technologies aim to transform plastic waste into something useful, it can be into another useful material, or into energy, etc. The recycling of plastics is already a common practice in many countries, however only some types of plastics are concerned, and MPs are not recycled. There are currently no means to reuse MPs although there’s a significant opportunity since WWTPs are already filtering some MPs.

d. Litter collection technologies

Litter collection technologies focus on the removal of plastic present in the environment. These technologies target visible plastics (not MPs) and act as a “cure” rather than preventing the problem. An exception is the case of technologies aimed at removing plastics at river mouths, before it enters the ocean. There is currently no mean to remove plastics from the sea floor, where the vast majority of plastics are located. Despite this, cleaning-up beaches, marinas and harbors, and preventing plastic to move from rivers to oceans are providing an important step in the fight against marine plastic pollution, as well as positive impact on the tourism industry, and raising social awareness about the issue.

III. Results & discussion

1. Review of technologies and estimated Technology Readiness Levels (TRLs)

The technologies available in the four different categories have been reviewed and summarized in figure 18. These categories cover the various ways to manage plastic pollution: (i) curing the problem when plastics is already in the ocean or rivers, (ii) transforming plastic or recycling it when it is collected, (iii) preventing plastic pollution by wastewater treatment to prevent in particular MPs to contaminate water, and (iv) technologies to monitor plastic litter in the environment.
Taken together, information on costs and effectiveness for marine litter management technologies is not always readily available, since many of these technologies are still in development stages. For each technology, we have estimated the Technology Readiness Level (TRL) as presented in the results and discussion chapter.

<table>
<thead>
<tr>
<th>Plastic litter removal</th>
<th>Plastic litter transformation</th>
<th>Wastewater Treatment</th>
<th>Monitoring of plastic marine litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Litter Containment Booming Set</td>
<td>Thermal treatment</td>
<td>Automated filtering system &amp; photocatalytic coating</td>
<td>FerryBox system</td>
</tr>
<tr>
<td>Seabin project</td>
<td>Lindenau WRS-System</td>
<td>Membrane technology</td>
<td>Microplastic analyzer &amp; mini-seawater sampling system “common sense”</td>
</tr>
<tr>
<td>The Ocean cleanup</td>
<td>“Recycling Technologies”</td>
<td>Rapid sand filtration</td>
<td>Marine Litter DRONET</td>
</tr>
<tr>
<td>SeaVax Robotic Vacuum Ship</td>
<td>“Plastic Mining Cooperation”</td>
<td>Disc filter</td>
<td>Monitoring of marine plastics from space</td>
</tr>
<tr>
<td>Baltimore Inner Harbor Water Wheel</td>
<td>Consumer goods made from ocean plastic, Econyl, Adidas &amp; Parley Shampoo, Ecoalf, and Many others</td>
<td>Dissolved air flotation</td>
<td>Monitoring of beach plastics bitter by webcam</td>
</tr>
<tr>
<td>RAM Europe beach cleanup machines</td>
<td>Enzymatic treatment</td>
<td>Bonus Cleanwater project</td>
<td>New remote sensing technologies in development</td>
</tr>
<tr>
<td>Marina trash skimmer</td>
<td>Compostable plastic bag</td>
<td>Water 3 project</td>
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<tr>
<td></td>
<td>Bioplastics</td>
<td>Anaerobic digestion</td>
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<td>High frequency vibrating screens (HFVS)</td>
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</tbody>
</table>

*Figure 18: Marine plastic litter technologies divided into four categories*
a. Wastewater treatment plants technologies

Technology 1: Automated filtering system & photocatalytic coating

Two wastewater treatment technologies will be developed in the CLAIM project: an automated filtering system to remove visible-sized MPs and a photocatalytic coating to reduce nano-level microplastic pollutants. The system involves coatings with material of nano-sized semiconductors that initiate and speed up a natural process of photocatalytic oxidation. The photocatalytic membranes were created in partnership with the Swedish company, PP Polymer AB. The two technologies are linked in that the filtering system is intended to optimize the operation of the coating equipment, although the former can also be installed on its own. Both technologies will be developed in order to be applied within the purification process of WWTPs.

Estimated TRL: 4

Technology 2: Membrane technology (MB)

MB is based on the principle of separating the activated sludge from the cleaned wastewater by filtering it through a physical barrier, a membrane with very fine pores, in general 0.02-0.4 µm. Air is blown (air scouring), over the membranes to keep them clean and remove slurry and particles that would clog the membranes. The membranes do not allow particles and particle bound pollutants to pass through, e.g. purification of bacteria, viruses, micro plastics and residual pharmaceutical agents. MB are implemented on key intervention points (water treatment plant) and prevent micro plastics to be released in the environment. Several test installations have been commissioned and have demonstrated purification performance and durability. The special membrane technology (VeSave) is designed to filter water without using pump energy, making it a more energy-efficient solution. It runs using the force of gravity. MB was tested with the following 3 other technologies. The following ranking list has been obtained regarding microplastic removal (Talvitie et al., 2017):

- MBR (99.9% removal)
- RSF (97% removal)
- DAF (95% removal)
- Discfilter (40 – 98.5%)

Estimated TRL: 7

Technology 3: Rapid sand filter (RSF)

Rapid sand filtration, in contrast to slow sand filtration, is a purely physical treatment process. As the water flows through several layers of coarse-grained sand and gravel, relatively large particles are held back safely. This filtering process is determined by two basic physical principles. First, relatively large suspended particles get stuck between the sand grains as they pass the filter medium (mechanical straining). Second, smaller particles adhere to the surface of the sand grains caused by the effect of the van der Waals forces (physical adsorption).

Estimated TRL: 7
Technology 4: Disc filter

Disc filters consist of two discs composing each of several filter panels. The particle removal is based on physical retention in filters and sludge cake formation inside the filter panels. The sludge cake formation decelerates the filtering, causing water level rise inside the cylinder. When water meets the level sensor, backwash is initiated.

Estimated TLR: 7

Technology 5: Dissolved air floatation (DAF)

In DAF, water is saturated with air at high pressure and then pumped to a flotation tank at 1 atm, forming dispersed water. The released air bubbles in dispersed water adhere to the suspended solids causing them to float to the surface, from where it is removed by skimming.

Estimated TLR: 7

Technology 6: Bonus Cleanwater project

The “Bonus Cleanwater” is an EU-funded project for exploring, developing and comparing new technologies for removing emissions of micro pollutants and MPs into the Baltic Sea. The project will use 4 innovative technologies which will be explored and further developed to reduce micro pollutants and MPs in wastewater focusing on finding solutions that are both cost- and energy efficient. The project combines fundamental studies on how the respective processes are controlled with applied ones, concerning safety of operation, cost of operation and assumed energy consumption: More energy efficient ways of ozonation will be explored and tested; Processes controlling the removal of micropollutants in moving bed biofilm reactors will be studied; Membrane based technologies will be studied with the aim to increase removal of both micro-plastics and micropollutants; and Biofilters will be studied for their potential to remove micropollutants and MPs in decentralized applications.

Estimated TLR: 3

Technology 7: Water 3 project

The University of Koblenz-Landau in Germany is leading the Water 3.0 research project on next generation technologies for removing MPs in wastewater. Through experimentation with hybrid silica gels, the project has discovered a way to remove MPs and pharmaceuticals from water. Pharmaceutical molecules chemically react with the gels, securely separating them from water, while MPs are treated with a gel that promotes the formation of clumps. The silica gel clumps accumulate to the size of ping-pong balls that float on the surface of the treatment basin, allowing for separation and removal. Testing is now underway.

Estimated TLR: 3
b. Monitoring plastic marine litter technologies

Technology 1: FerryBox system

In the CLAIM project, a technology will be developed which focuses on marine microplastic monitoring. This will provide a passive prototype filtering system to be placed in the existing flow through FerryBox system circuit. The first Ferryboxes recorded data on plankton, subsequently more sophisticated technologies were developed which can observe multiple water quality features. Ferryboxes have advantages over other forms of “automated” monitoring such as:

- Ship energy is sufficient to include complex systems
- Location inside ship is sheltered to prevent damage including biofouling
- Maintenance can take place at harbors (unlike for buoys and platform)
- A transect is produced rather than single location data

A distinction should be made between FerryBox operating institutions – i.e. those who manage the ferry boxes and the data they collect, and the FerryBox carrier, i.e. the operator of the ship carrying the FerryBox. Foreseeably both actors are relevant to the uptake of the CLAIM technology.

Estimated TLR: 5

Technology 2: Microplastic analyzer & mini-seawater sampling system.

This EU-funded project which was completed in February 2017, focused on the development of sensors to detect different environmental pollutants in sea water (including noise, eutrophication, MPs and heavy metals). This included the development of a “sensor to measure and quantify the surface concentration of small plastic particles (MPs) in the off-shore environment”. The project developed one sensor relevant to microplastic monitoring - COMMON SENSE MPs Analyzer and MISS (Mini-Seawater Sampling) System. This combines a microplastic monitoring system and an autonomous sampling system based on niskin bottles. The sensor allows for in situ monitoring of water in real time, based on “automated optical interrogation techniques”. The MPs sensors have now been deployed on a number of vessels.

Estimated TLR: 6

Technology 3: Marine Litter DRONET

Marine Litter DRONET aims at developing a simple, repeatable and accurate method for surveying marine litter with drone technology. The initial focus is on aerial drones for coastlines. The Survey Methodology developed will eventually be integrated with global efforts to develop coordinated Marine Litter protocols. For example, the current version of the drone survey methodology, initially developed by The Plastic Tide, is based on the OSPAR Marine Litter protocol.

The Marine Litter DRONET supports the Plastic Tide’s mission by bringing together different people, organizations, NGOs in a global network. Members of the network contribute by sharing images they
have captured from beach surveys to help train the algorithm and/or help develop and improve the survey methodology.

**Estimated TLR: 2**

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**Technology 4: Monitoring of marine plastics from Space**

ESA (European Space Agency) is investigating detection of floating plastic litter from orbit. Indirect measurements from space are already used to get to grips with the marine plastic litter problem. For instance, satellite maps of ocean currents let us simulate accumulation of litter in vast gyres within the Pacific, Atlantic and Indian Oceans. The new project is to assess the feasibility of direct optical measurement of seaborne plastic waste from satellites. It is not about spotting floating litter items but instead to identify a distinct spectral signature of plastic picked up from orbit, in the same way that processing software can today pick out concentrations of phytoplankton, suspended sediments and water-borne pollution. In particular, plastic has specific infrared fingerprints that are sometimes used in the recycling industry to sort plastic items from other refuse on a conveyor belt. Supported by ESA’s Basic Activities, two teams are working in parallel, led by Argans Limited and Plymouth Marine Laboratory in the UK. Satellite images from missions such as the Copernicus Sentinels are being checked against aerial coverage plus ground surveys where drifting plastic is collected from the sea to be assessed in close-up.

**Estimated TRL: 2**

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**Technology 5: Monitoring of beach litter by webcam**

Recently, researchers developed an imaging method to detect colored, macro-plastic debris on beaches based on a webcam located in Japan that makes continuous automatic monitoring possible (Kako et al., 2010; Katoka et al., 2012).

**Estimated TRL: 2**

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**Technology 6: New remote sensing technologies coming up?**

Monitoring phytoplankton in surface oceans is one example of the changing use of technology. Up until the late 1970s, phytoplankton was measured much the same way that we are currently measuring plastic, with nets towed behind ships. Sensors on satellites measuring chlorophyll, the photosynthetic pigment in plankton, have replaced the net method.

Remote sensing methods have many advantages over surface sampling, including surveying large areas over relatively short timescales. For oceanography, this is a great step forward because the ocean is vast and ship time is expensive. It also provides a more complete picture as collecting with nets is a slow business and generally only covers a narrow area. There also tends to be long stretches of time between sampling efforts.
Recently, there has been interest in applying remote sensing technologies to the plastic pollution problem. Plastics have characteristic absorbance and reflectance spectra in the near infrared part of the optical spectrum, which is in the same range as the reflectance spectra for chlorophyll. The potential for using remote sensing techniques to monitor plastic debris exists. In fact, NIR cameras and spectrometers are used in recycling facilities to sort the different types of plastic and colors. However, a major limitation of this technique is that the NIR spectra are absorbed by water, so if the plastic is not at the surface of the water, it would not be picked up with this technique. Raman spectroscopy is another tool that is used in recycling facilities and does not have the same limitation in water. It does, however, need an active light source, something other than the sun. The use of NIR spectroscopy has been demonstrated to be able to detect small plastic pieces mixed with beach sand. Both of NIR and Raman techniques suffer from spatial resolution issues in this application because most of the plastic found in oceans is so small; smaller than a pencil eraser.

One promising way of getting around this issue is by doing surveys using unmanned vehicles—aerial, underwater or even surface (water) vehicles. Since these vehicles are generally much smaller and more agile than a boat or a helicopter/airplane, the sensors deployed on them would be able to get closer to the survey area, enabling better imaging. In the case of Raman spectroscopy, another possibility is to create a small field deployable sensor that could be used in shipboard screening or deployed on buoys.

Estimated TRL: 2

c. Plastic litter transformation technologies (recycling)

Technology 1: Thermal treatment

The CLAIM project will develop and demonstrate in the field a portable, self-contained thermal treatment device for the recovery of energy from collected visible macro plastic litter, aiming to provide a short term, pragmatic approach to speeding up the removal of floating litter from the sea. The device under development is effectively a small-scale version of technology used in large waste to energy plants and consists of a pre-treatment system (metal extraction and shredder) and a system for the production and exploitation of syngas from the breakdown of macro plastics, based on high temperature plasma pyrolysis. Pyrolysis differs from gasification and combustion in that it is an endothermic process, meaning that it requires energy in the form of heat to carry out the reaction (ref. review of the options for the thermal treatment of plastics, EPIC, 2004). It also contains a novel, self-adapting control system to ensure the highest possible levels of efficiency. The device will allow the recovery of embedded energy from collected litter and/or plastic fishing gear, to be used either directly by the treatment system or by connected utilities. This technology will be designed to be used both on board marine litter collection vessels and in port facilities. The project will also assess the cost-effectiveness of using the device on board ships for energy production as a contribution to the circular economy.

Estimated TRL: 5

Technology 2: Lindenau WRS-System

The Lindenau WRS-System is a ship-based sustainable waste management system for use in island states and large cities at coasts or at rivers. trialed in Cape Verde, the technology is located on board 2 converted processing ships which are permanently moored in the port of Praia. Another ship travels
around the islands weekly, collecting waste to be processed. The Waste-Recycling-Ship (WRS) is a complete national waste management system that deals with waste from the island chain of Cape Verde. The benefits of this system is it manages waste from entering the ocean, since these are island chains if waste is improperly managed it could easily end up in the ocean. However, it does not specifically manage ocean or beach waste, and is more of a prevention tactic that happens to be based on a ship. The system is said to be economically feasible as waste treatments plants may not find ample space for such a large plant to be built on an island or in a coastal environment. A feasibility study was conducted for this system; however, it seems from literature that this was never implemented.

**Estimated TRL: 4**

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**Technology 3: British company “Recycling Technologies”**

Recycling Technologies converts end-of-life plastic into oil. It has developed the patented RT7000, a chemical recycling machine capable of processing up to 7,000 MT of plastic waste per year. Essentially it is a chemical recycling process to convert unsorted plastic waste into a valuable low Sulphur hydrocarbon called ‘Plaxx’. The feedstock preparation module consists of a separation system that scans the material. Undesired items, such as residual stones and glass, are rejected post scanning. The prepared material is then shredded and dried prior to be fed into the thermal cracker where the long carbon chains in plastics are cracked into shorter chains. The hot hydrocarbon vapor leaving the reactor enters the product separation module, where it is filtered and treated for impurities such as solid particulates and unwanted chemical compounds. The refined gas is condensed into “Plaxx”. Plaxx can be in the form of light oil (suitable as a feedstock for virgin plastic production), low Sulphur heavy fuel oil (suitable for use in marine engines), base oil (for use by lubricant oil producers) or wax (suitable for coatings, injection moldings and candles). The RT7000 is transportable and mass-producible, with a per unit footprint of 30×30 m², allowing it to be located at existing plastic waste handling facilities.

**Estimated TRL: 9**

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**Technology 4: Dutch start-up Plastic Mining Cooperation**

The Plastic Mining Cooperation is a start-up company that develops a tailor-made solution for plastic waste on islands and coastal areas. Cooperating with local environmental organizations and waste management companies they aim at turning waste into a resource.

Plastic Mining Cooperation is developing a tailor-made solution for plastic waste on islands and coastal areas. This involves them providing an industrial mobile recycling machine to shred, wash and dry collected plastic waste, which can then be bagged and shipped for use as raw material. The Plastic Mining Cooperation has a 3-year ‘Plastic Mining Recycling Program’ which helps Small Island Development States to enable a circular economic model for plastic waste. The program includes an awareness program, mobile recycling machine, trading platform and access to monitoring and data. The program is still in launch phase. No information online can be found regarding costs or effectiveness of the program.

**Estimated TRL: 8**
Recycling marine waste plastics can also be implemented to develop consumer products, not for producing energy, oil or transformed plastics. Such projects include:

**ECONYL:**

Collect nylon waste from fishing nets. They are cleaned, shredded, compacted, bagged and transported to the Econyl regeneration plant in Ljubljana, Slovenia. The polymer is de- and re-polymerised and turned into ECONYL® nylon yarn which can then be used as raw material, e.g. for the production of sportswear or carpet products. It is claimed that Polyamide 6 waste can be regenerated an infinite number of times, thereby offering a substitute to virgin raw material.

*Estimated TRL: 8*

**ADIDAS & PARLEY FOR THE OCEAN:**

Partnership between Adidas and Parley to produce sportswear from plastics intercepted at beaches and coastlines before it enters the ocean. Adidas claims that it makes 1 million pair of shoes in 2017 from these recycled plastics. In a first step the plastic is collected by Parley and its partner organizations in coastal areas. It is then being shipped to Adidas x Parley’s supplier in Taiwan which upcycles the plastic and transforms it into yarn fibers, which are then used to create adidas x Parley products.

*Estimated TRL: 8*

**Partnership between Procter & Gamble, TerraCycle and Suez**

...to produce Head & Shoulders shampoo bottles made with 25% recycled beach litter collected by volunteers. Collection of the plastic from beaches in the U.K. and France and initial sorting of the material is handled by TerraCycle. The collection of 2,600 tons of PCR beach plastic for the project was enabled through relationships with NGOs, non-profits, and other organizations already engaged in regular beach cleanups. At the TerraCycle facility, operators sort through the materials manually to remove non-plastic items. From there, the plastic is sent to SUEZ where it is shredded, cleaned, and sorted again into specific plastic categories. Sorted, pure high-density polyethylene is then used as part of the resin mix (25%) for the Head & Shoulders bottle.

*Estimated TRL: 8*

**ECOALF’s Upcycling the Oceans**

(UTO) project that collects ocean waste and turns it into top quality yarn (textile) to produce fabrics and products. The project started in September 2015 in Levante (Spain). 9 fishing ports from the provinces of Castellón and Alicante decided to collaborate and they managed to remove more than 60 MT of trash. In 2016, Ecoembes joined the project which was extended to the provinces of Girona, Barcelona, Tarragona and Valencia. To date, 28 ports, amounting to a total of 441 sea trawlers are involved. The project is currently expanding, including replication of the project in Thailand. The Ecoalf Foundation has managed to involve Spanish companies that are leaders in their respective areas (from waste management companies, technological centers and recyclers, to thread and fabric manufacturers) that
will collaborate in this project and share their experience in recycling different types of debris (PET bottles, fishing nets, used tires, etc.)

Estimated TLR: 8

Several other initiatives of this type are implemented

As recycling plastics has apparently become a marketing strategy. Here are some examples:

✓ The San Francisco footwear brand Rothy’s sells women’s seamless round-toe flats and pointed-toe flats, made using recycled PET plastic yarn in a 3D knitting process.
✓ Hamilton Perkins Collection Earth Bags are convertible duffel-to-backpack vessels made from 100% recycled plastic bottles.
✓ The products of California company Green Toys are made 100% from recycled milk jugs.
✓ Nike makes the USA National Soccer Team polyester shirt and shorts pictured here using yarn made with recycled plastic from bottles. Through this and many other applications of the yarn brand-wide, from professional sports to consumer goods, Nike says it has saved more than 3 billion plastic bottles from the landfill.
✓ Pilot’s Bottle 2 Pen line consists of gel roller pens made from 89% post-consumer recycled bottles, and ballpoint pens made from 83% recycled bottles.
✓ Preserve is a Corporation that makes bath, kitchen, and tabletop products in the U.S. from recycled yogurt cups and other #5 plastics.
✓ Norton Point has developed sunglasses made with recovered ocean plastics, particularly high-density polyethylene (HDPE) used to make plastic milk jugs, laundry detergent bottles, and shopping bags. For every product they sell, the company commits to clean up one pound of plastics from the ocean.
✓ Lush cosmetic company has partnered up with Ocean Legacy, an organization that collects plastic litter from the Pacific Ocean, to make bottles and pots for its products. The company even rewards its customers for recycling—when they return five clean and empty pots to a store, they get a free face mask.
✓ Freeride recycled plastic skateboards features a deck made from 100% recycled plastic.
✓ Reusable bags from Ecoruzi made from 100% certified recycled PET.
✓ Blue Planet sunglasses feature recycled plastic frames.
✓ ReFleece iPad sleeves are made from post-consumer fleece jackets and recycled PET.
✓ Bumper Bed from WestPaw make dog beds cushioned with fiber filling that is made entirely from recycled plastic bottles.
✓ EcoSaucer Flying Disk from Green Toys is made from recycled plastic bags.
✓ Simple Flippee Sandals are manufactured using 100% recycled materials, including an upper webbing made from recycled PET.
✓ Outdoor rugs from Fab Habitat are made from tightly-woven recycled plastic straws.

d. Litter collection technologies

Technology 1: Marine Litter Containment Booming Set

This is one of the technologies under study by the CLAIM project. It is composed of a U-shaped floating barrier for marine litter containment. The innovative feature of the technology is given by the interchangeable screens of variable mesh sizes which allow to capture litter of variable sizes and the efficient design to prevent clogging. The technology will allow to capture visible litter (d>1mm) and
will be located in key river discharge areas. Cameras will also be installed to monitor the collection of litter. Photo (just an illustration – it is not a photo of the claim technology) is taken from pollution control boom / floating:

**Estimated TRL: 4**

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**Technology 2: Seabin project**

The Seabin is a floating rubbish bin that is located in the water at marinas, docks, yacht clubs and commercial ports. The Seabin moves up and down with the range of tide collecting all floating rubbish. Water is sucked in from the surface and passes through a catch bag inside the Seabin, with a submersible water pump capable of displacing 25,000 liters per hour, plugged directly into 110/220 V outlet. The water is then pumped back into the marina leaving litter and debris trapped in the catch bag.

**Estimated TRL: 7**

---

**Technology 3: The Ocean Cleanup**

It is a floating system composed of a U-shaped 2 km long floater, an impermeable screen to catch sub-surface plastics, a sea anchor to slow down the system so as it moves slower than plastics, and a support vessel to bring the collected litter back to land. The Ocean Cleanup states their technologies can remove 50% of the Pacific garbage gyre in 5 years, and that the plastic will be recycled or sold. Pilot systems have been deployed in the North Sea in 2016 and 2017 and deployment is scheduled for mid-2018. No information about effectiveness was publicized by The Ocean Cleanup. The technology may not be ready to deploy or economically feasible depending on the effectiveness of the technology.

**Estimated TRL: 2**

---

**Technology 4: Seavax robotic vacuum ship**

A satellite-controlled aluminum platform powered by sun and wind acting as a vacuum to collect litter of all sizes. Sonar technology protects marine and bird life from getting caught in the vessel. The SeaVax is ‘economical’ because it uses a modular design that can work anywhere in the world. The cost to cleanup is $1.9 or € 1.22 per kilogram. SeaVax’s project director has stated that “huge fishing nets to deadly micro particles can be swept or sucked up, ground down and stored in SeaVax’s tanks” (Frost, 2016). Small scale prototypes for the SeaVax have been made but nothing on the scale intended for oceanic use.

**Estimated TRL: 2**

---

**Technology 5: Baltimore Inner Harbor Water Wheel**
The Inner Harbor Water Wheel combines old and new technology to harness the power of water and sunlight to collect litter and debris flowing down the river. The river’s current provides power to turn the water wheel, which lifts trash and debris from the water and deposits it into a dumpster barge. When there isn’t enough water current, a solar panel array provides additional power to keep the machine running. When the dumpster is full, it’s towed away by boat, and a new dumpster is put in place. The collected material is weighed and separated into different categories: plastic bottles, polystyrene containers, cigarette butts, glass bottles, grocery bags and chip bags. Some of the trash is incinerated to help generate electricity for the city.

**Estimated TRL: 8**

---

**Technology 6: RAM Europe beach cleanup machines**

The series of beach cleaning machinery manufactured by RAM EUROPE include special attachments which are suitable for the pre-cleaning of beaches. By using these attachments, it is possible to accumulate the materials having performed the stirring up of the sand in an adjustable depth and load them on vehicles. The whole work is performed without removing the sand and degrading the beach form. The pre-cleaning attachments are mounted not only on beach cleaning machines which perform the final cleaning of the beach but also on other machines, such as multipurpose vehicles, tractors etc. RAM EUROPE manufactures a variety of beach cleaning machines, including automotive machines and machines towed by multipurpose vehicles. In addition, there are small hand-driven machines for small beaches. For beaches with pebbles, they use vacuum cleaning machines for waste removal.

**Estimated TRL: 9**

---

**Technology 7: Marina trash Skimmer**

The Marina Trash Skimmer (MTS) has been designed for the removal of trash and pollutants and to operate in all water conditions. Working permanently, it collects trash and floating debris from the surface of the water. The MTS is a stationary unit that should be strategically placed at a specific problem site. Working with the installations sites natural currents, tides and prevailing winds. It has been used by the Newport Harbor Marina and several others marinas in the USA during their 2016. No information is available on effectiveness and durability. It is commercially available.

**Estimated TRL: 7**
2. SWOT analysis

### SWOT Matrix Litter Transformation

<table>
<thead>
<tr>
<th><strong>STRENGTHS (+)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Thermal treatment (i.e. energy recovery) may be considered a viable option for some plastic waste collected from the sea, in particular for plastic that has been in the sea for long enough to become too degraded or contaminated for material recycling</td>
</tr>
<tr>
<td>• Recycling plastics cuts back on oil consumption. Helps to extend the lifespan of fossil fuel reserve.</td>
</tr>
<tr>
<td>• Recycling uses energy but less than making fresh plastic</td>
</tr>
<tr>
<td>• Plastic recycling is a well-established industry</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>WEAKNESSES (−)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Transformation processes currently involve visible plastics, but recycling opportunities have not yet been found for microplastics.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>EXTERNAL FACTORS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPPORTUNITIES (+)</strong></td>
</tr>
<tr>
<td>• New technologies involving different inputs, outputs, scales and processes are changing the market</td>
</tr>
<tr>
<td>• Recycling plastics can be an alternative to landfill potentially causing environmental harm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>THREATS (−)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Recycling may be seen as disincentive for avoiding the continuous increase of plastic production.</td>
</tr>
<tr>
<td>• Recycling plastics delays rather than avoids final disposal</td>
</tr>
</tbody>
</table>

### SWOT Matrix WWTP

<table>
<thead>
<tr>
<th><strong>STRENGTHS (+)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Can remove effectively microplastics</td>
</tr>
<tr>
<td>• Point of intervention (wastewater treatment plants) is where effluents are treated and infrastructures are already in place</td>
</tr>
<tr>
<td>• Membrane waste water technology is the only technology that has been reviewed for effectiveness in a peer reviewed journal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>WEAKNESSES (−)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• The costs of developing and employing WWTP technologies to remove microplastics may be inhibitive</td>
</tr>
<tr>
<td>• All other technologies (apart from membrane technology) only have organizational reports or data to support their effectiveness information, and most have no information available at all.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>EXTERNAL FACTORS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPPORTUNITIES (+)</strong></td>
</tr>
<tr>
<td>• The magnitude, complexity and urgency of the issue of microplastics in marine environments require a mix of measures (cure and prevention) from design of products, via users to end-of-pipe.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>THREATS (−)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Different regulatory measures up-stream may be more cost effective and efficient than end-of-pipe solutions. Examples of such measures might be bans on the use of plastic microbeads in personal care products or product standards requiring appropriate filters to be installed in washing machines to avoid leakage of plastic microfibers</td>
</tr>
</tbody>
</table>
### SWOT Litter Collection

#### Internal Factors

**Strengths (+)**

- Focuses efforts on beach clean-ups where plastics are in high concentrations.
- Preventing plastic litter to enter the oceans by cleaning-up at river mouths.
- Can be put in place at specific hotspots in e.g. rivers where technologies would result as most effective (high concentration of plastics).
- Plastics collected is a useful source of information on the monitoring of marine litter presence. Hence useful for conceiving appropriate measures against plastics pollution.

**Weaknesses (−)**

- Only address a minor part of the problem: 94% of the plastic that enters the ocean ends up on the sea floor. No technology or actions is available to access and remove plastics on the sea floor.
- Prevention is preferable to cure. Carrier bag charges have already proved a cost effective step in the right direction, and the same approach could be taken to other commonly littered plastic items. Deposit refunds on beverage containers would help incentivize people to return them for recycling, and reduce the amount littered.
- No technology is available to remove nautical plastics already in the oceans.
- Does not prevent additional litter to get in the oceans.

#### External Factors

**Opportunities (+)**

- Reducing plastic litter on land will result in a reduction of plastic marine litter.
- The amount estimated to be on beaches globally is not the largest (5%), but importantly, the concentration is very high, at 2,000 kg/km², and access is easy.
- Cleaning-up beaches has a visual impact (gain of aesthetic value). It also raises social awareness and enhances public perception, hence it may be an incentive to avoid plastic littering. It also has a positive impact on the economy (tourism).
- Can promote useful initiatives such as eco-labels and standards applied to beach sites to ensure compliance with stringent environmental and safety requirements.

**Threats (−)**

- Small amount of plastic floating at a low concentration.
- Cleaning-up marine plastic litter may indirectly favor plastic littering.
- Cleaning-up actions may give the wrong impression that the cleaning can be effective and complete, although this is not the case, (except for beaches).
- Obstruction of sea traffic - Due to the size and location of the technology (e.g. river mouths), its implementation might represent an obstruction to sea traffic and therefore a barrier to its feasibility.
- Unintentional bycatch - accidental catch of protected species.
- Ownership of the collected plastics might become an issue, in particular if it generates revenues via recycling or transformation into new products.

### SWOT Monitoring

#### Internal Factors

**Strengths (+)**

- Uses a combination of complementary methods.
- Coordinated monitoring (information sharing).

**Weaknesses (−)**

- Detailed monitoring of marine litter is difficult, expensive and ultimately, perhaps, unnecessary (to some extent).
- Adopting the “best available technology” approach will allow efforts and resources to be focused on measures that are very likely to reduce the problem instead of being diverted into assessing how much worse it is getting.
- The biggest problem with getting good data is the massively varying abundance of litter depending on when and where you measure. Litter moves between beaches, the water column, and the sea bed depending on the season and the weather.

#### External Factors

**Opportunities (+)**

- Knowledge of the sources and fate of plastics in the marine environment is far from complete. There is a knowledge gap.
- Without good information, it is difficult for policy makers and other concerned parties to know where to target efforts in order to yield the greatest impact. Monitoring marine litter is an essential tool to help address this form of pollution.
- If targets to reduce plastics are to be effective as a means to stimulate action, we need reliable monitoring to see progress towards these targets and effectiveness of measure taken.

**Threats (−)**

- Critical information necessary to act has already been estimated: Amount of plastic (% of total and concentration) for the sea floor, floating plastics, and beaches.
- Hence the risk is that monitoring is considered as a lower priority as compared to preventing or curing actions.
### 3. Overall results

<table>
<thead>
<tr>
<th>SWOT analysis</th>
<th>Impact</th>
<th>TRL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main strength</strong></td>
<td><strong>Main Weakness</strong></td>
<td><strong>Main Opportunity</strong></td>
</tr>
<tr>
<td>Marine litter Containment</td>
<td>Boomng Set</td>
<td>4</td>
</tr>
<tr>
<td>Seabing project</td>
<td>7</td>
<td>low</td>
</tr>
<tr>
<td>The Ocean Cleanup</td>
<td>2</td>
<td>low</td>
</tr>
<tr>
<td>SeaVax Robotic Vacuum Ship</td>
<td>2</td>
<td>low</td>
</tr>
<tr>
<td>Baltimore Inner Harbor Water Wheel</td>
<td>8</td>
<td>medium</td>
</tr>
<tr>
<td>RAM Europe beach cleanup machines</td>
<td>9</td>
<td>high</td>
</tr>
<tr>
<td>Marina trash skimmer</td>
<td>7</td>
<td>low</td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>5</td>
<td>high</td>
</tr>
<tr>
<td>Lindenau WRS-System</td>
<td>4</td>
<td>medium</td>
</tr>
<tr>
<td>Recycling Technologies</td>
<td>9</td>
<td>high</td>
</tr>
<tr>
<td>Plastic Mining Cooperation</td>
<td>8</td>
<td>high</td>
</tr>
<tr>
<td>Consumer goods from ocean plastics</td>
<td>8</td>
<td>low</td>
</tr>
</tbody>
</table>

### Litter removal

<table>
<thead>
<tr>
<th>Plastic Litter removal</th>
<th>Impact</th>
<th>TRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach clean-up</td>
<td><em>Only address minor part of the problem</em></td>
<td>4</td>
</tr>
<tr>
<td>Raise social awareness</td>
<td>None</td>
<td>4</td>
</tr>
</tbody>
</table>

### Litter monitoring

<table>
<thead>
<tr>
<th>Litter monitoring</th>
<th>Impact</th>
<th>TRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need for informed policies</td>
<td><em>Knowledge of fate of plastics information available to take actions</em></td>
<td>5</td>
</tr>
<tr>
<td>Difficult and expensive</td>
<td><em>Microplastic analyzer &amp; mini-seawater sampling system “common sense”</em>*</td>
<td>6</td>
</tr>
</tbody>
</table>

**Figure 19: Table of technologies found for the four categories (Monitoring, Clean-up, Transformation, and Wastewater treatment)**
Figure 19 groups together all elements for each technology reviewed in each family of solutions: the main characteristics of the SWOT matrix, the derived estimation of their environment, economic and social impact, and the estimated TRL for each category. One technology appears to have a high TRL as well as several high impacts:

- **Plastic removal**: The Ram Europe beach clean-up machine, as a well-established technology, with easy access on key intervention points with the highest concentration of plastics, and with quick impact on cleaning up beaches with direct impact on tourism industry and services, and social awareness.

- **Plastic transformation**: Recycling technologies, plastic mining corporation and consumer goods from recycled plastic are both mature technologies and appear likely to also have a social impact on small islands where the need is high for urgent solutions.

- **Wastewater treatment technologies** are crucial and may have high impact from the economic, social and environmental point of view, and focus on key intervention point where waste water is collected and treated, hence where actions should focus. What makes the difference in these categories is the TRL. Membrane technology appear to be the only one with test having been commissioned and have demonstrated purification performance and durability. It also concerns a particularly difficult issue of MPs and the ability to prevent them to get into the rivers and oceans.

- **Regarding Monitoring**, two technologies are very close to each other, FerryBox and the combination of microplastic analyzer and mini seawater sampling system “common sense”. The latter has some advantage in terms of TLR given his previous experience in a past EU project and testing already done to some extent.

It is clear that the above SWOT analysis and estimated TRL and impacts should be seen as only one step which needs more in-depth research and analysis to make decisions. It is difficult to address uncertain or two-sided factors such as factors that could be both a strength and a weakness with a SWOT analysis. In addition, interesting emerging technologies such as the space monitoring of plastics would generate a lot of interest and application if preliminary results are further developed.

The review of technologies and the findings of this research project point to the following preliminary results regarding how to tackle the problem of plastic marine litter:

- There are limitations to the data available on the flows and stocks of marine plastic litter, and there would be significant value in further studies.
- There is also limited information about the costs and effectiveness of competing technologies, most of them in the development stages. The available information often cannot be verified or validated. Hence it is difficult to draw solid conclusions on cost-effectiveness at this moment.
- Despite the high profile of projects intended to clean up plastics floating in mid-ocean, relatively little actually ends up there, and this approach appears to be of limited value.
- Prevention is preferable to cure, and the greatest opportunity to prevent plastic entering the oceans is to take steps to reduce plastic litter generation on land.
- Technologies should be adapted to the social and industrial context of the point of intervention, and finally,
- There’s a need to develop long term (calling for basic research) and short-term approaches at the same time.
Conclusion and recommendations

We live in the age of plastics. They are ubiquitous in our daily life and in many industrial applications. They play a major role in our economy. Their production continuously increases. However, plastics are not well managed and found their way to the oceans, leading to far-reaching environmental, health, social and economic impacts. Hence the challenge is to maintain the economic and societal benefits brought by plastics but avoiding that they end up in the environment.

This paper aims at providing elements of response to 3 main research questions:

➢ Where marine plastic waste comes from, where it goes, and what is its impact? Hence where to focus attention?

Although there are knowledge gaps, the key elements are clear: 80% of marine litter is plastics. 94% is on the sea floor, only 1% if floating. Half of the plastic litter is single use plastics (SUP). Microplastics are tiny but are becoming a big threat. Marine plastics is found in high concentration on beaches, two orders of magnitude higher than anywhere else. The key points of intervention are therefore beaches, wastewater treatment plants, and rivers. Floating plastics might therefore be less important than it can appear in the media.

➢ What are the existing (and being developed) efforts, actions and technologies to reduce plastic marine litter? Hence where are possible opportunities to focus on? Do they have the right balance between cure and prevention?

Many efforts are being implemented at all levels, local, national, European, G7 and worldwide. However, plastics remain overall wrongly managed, in particular in Asia (China and South East Asia). Social awareness is increasing but so do the plastic ending into oceans. There is no one magic bullet solve-it-all solution. What counts most is the coherence between different solutions to form a strong package of measures.

➢ Are these efforts – in particular the technologies - put in the right place (key intervention points)? And which are the preferred options given their estimated Technology Readiness Level and their potential environment, economic and social impact?

Following SWOT analysis of 4 main categories: (i) plastic removal, (ii) transformation/recycling, (iii) WWTP, and (iv) monitoring, and the reviews of 30 corresponding technologies with their TRL estimated, the outcome indicates that the preferred solution in each category are:

- Beach clean-up as it is easy access, highly concentrated and strong economic benefits
- Membrane technology appears the best technology for filtering microplastics and this can be operated in the key intervention point of WWTPs
- Monitoring is necessary for informed policies but likely to be difficult and expensive. The FerryBox system appears the most promising but monitoring from space might be the technology that can bring a change of paradigm as it did some years to measure plankton
- Regarding transforming and recycling the tailor-made solution of Dutch start up “The Plastic Mining Cooperation” that develops for plastic waste on islands and coastal areas appears the “best” one, also cooperating with local environmental organizations and waste management companies they aim at turning waste into a resource.

Overall, 3 main conclusions emerge from this research project:

- Prevention is better than cure. There is still no solution found for the 94% of plastics on the sea floor,
- One size does not fit all. Technologies should be adapted to the social and industrial context of the point of intervention, and
Need to develop at the same time long term and short-term approaches. It will be a long journey, but it starts now.

In this context and given the uncertainties and ongoing technological development, the following main strategic orientations are recommended: improving the economic and quality of plastic recycling; decreasing plastic waste and littering; more investments, research and innovation towards a circular economy approach for plastics; coordinate efforts of governments at international level; coordinate the public and private actions; and promote the combination of several technologies; focus action on the key points of intervention where measures are the most effective.
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Abstract


Cover photo retrieved from: https://usbeketrice.com/article/meme-si-vous-posez-un-plastique-au-sommet-de-l-himalaya-il-finira-dans-l-ocean
Appendix

Appendix 1: Waste estimates for 2010 for the top 20 countries ranked by mass of mismanaged plastic waste (in units of millions of metric tons per year) (Jambeck et al. 2015).

Legend: “Econ classif., economic classification; HIC, high income; UMI, upper middle income; LMI, lower middle income; LI, low income (World Bank definitions based on 2010 Gross National Income). Mismanaged waste is the sum of inadequately managed waste plus 2% littering. Total mismanaged plastic waste is calculated for populations within 50km of the coast in the 192 countries considered. pop., population; gen., generation; ppd, person per day; MMT, million metric tons” (Jambeck et al. 2015).

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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>UMI</td>
<td>262.9</td>
<td>1.10</td>
<td>11</td>
<td>76</td>
<td>8.82</td>
<td>27.7</td>
<td>1.32–3.53</td>
</tr>
<tr>
<td>2</td>
<td>Indonesia</td>
<td>LMI</td>
<td>187.2</td>
<td>0.52</td>
<td>11</td>
<td>83</td>
<td>3.22</td>
<td>10.1</td>
<td>0.48–1.29</td>
</tr>
<tr>
<td>3</td>
<td>Philippines</td>
<td>LMI</td>
<td>83.4</td>
<td>0.5</td>
<td>15</td>
<td>83</td>
<td>1.88</td>
<td>5.9</td>
<td>0.28–0.75</td>
</tr>
<tr>
<td>4</td>
<td>Vietnam</td>
<td>LMI</td>
<td>55.9</td>
<td>0.79</td>
<td>13</td>
<td>88</td>
<td>1.83</td>
<td>5.8</td>
<td>0.28–0.73</td>
</tr>
<tr>
<td>5</td>
<td>Sri Lanka</td>
<td>LMI</td>
<td>14.6</td>
<td>5.1</td>
<td>7</td>
<td>84</td>
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<td>5.0</td>
<td>0.24–0.64</td>
</tr>
<tr>
<td>6</td>
<td>Thailand</td>
<td>UMI</td>
<td>26.0</td>
<td>1.2</td>
<td>12</td>
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<td>3.2</td>
<td>0.15–0.41</td>
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<td>13</td>
<td>69</td>
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<td>3.0</td>
<td>0.15–0.39</td>
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<td>8</td>
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<td>UMI</td>
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<td>1.52</td>
<td>13</td>
<td>57</td>
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<td>2.9</td>
<td>0.14–0.37</td>
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<tr>
<td>9</td>
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<td>LMI</td>
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<td>0.79</td>
<td>13</td>
<td>83</td>
<td>0.85</td>
<td>2.7</td>
<td>0.13–0.34</td>
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<tr>
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<td>LI</td>
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<td>0.43</td>
<td>8</td>
<td>89</td>
<td>0.79</td>
<td>2.5</td>
<td>0.12–0.31</td>
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<tr>
<td>11</td>
<td>South Africa</td>
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<td>12</td>
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<td>2.0</td>
<td>0.09–0.25</td>
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<td>0.34</td>
<td>3</td>
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<td>0.60</td>
<td>1.9</td>
<td>0.09–0.24</td>
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<tr>
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<td>UMI</td>
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<td>1.2</td>
<td>12</td>
<td>60</td>
<td>0.52</td>
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<td>0.08–0.21</td>
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<tr>
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<td>1.77</td>
<td>12</td>
<td>18</td>
<td>0.49</td>
<td>1.5</td>
<td>0.07–0.19</td>
</tr>
<tr>
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<td>Pakistan</td>
<td>LMI</td>
<td>14.6</td>
<td>0.79</td>
<td>13</td>
<td>88</td>
<td>0.48</td>
<td>1.5</td>
<td>0.07–0.19</td>
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<td>1.03</td>
<td>16</td>
<td>11</td>
<td>0.47</td>
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<td>0.07–0.19</td>
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<tr>
<td>17</td>
<td>Burma</td>
<td>LI</td>
<td>19.0</td>
<td>0.44</td>
<td>17</td>
<td>89</td>
<td>0.46</td>
<td>1.4</td>
<td>0.07–0.18</td>
</tr>
<tr>
<td>18*</td>
<td>Morocco</td>
<td>LMI</td>
<td>17.3</td>
<td>1.46</td>
<td>5</td>
<td>68</td>
<td>0.31</td>
<td>1.0</td>
<td>0.05–0.12</td>
</tr>
<tr>
<td>19</td>
<td>North Korea</td>
<td>LI</td>
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<td>0.6</td>
<td>9</td>
<td>90</td>
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<td>0.05–0.12</td>
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<td>HCI</td>
<td>112.9</td>
<td>2.58</td>
<td>13</td>
<td>2</td>
<td>0.28</td>
<td>0.9</td>
<td>0.04–0.11</td>
</tr>
</tbody>
</table>

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

Appendix 3: Global Solid Waste Composition (Hoornweg & Bhada-Tata, 2012).
Appendix 4: Infographic summarizing plastics in the marine environment, where do they come from? Where do they go? (Eunomia Research & Consulting Ltd., 2016)

Appendix 5: Cost-Benefit Analysis (CBA) (Brander & Beukering, 2016)
Appendix 6: Multi-Criteria Analysis (MCA) (Brander & Beukering, 2016)

Appendix 7: Cost-Effectiveness Analysis (CEA) (Ayele et al., 2016)

Appendix 8: Delphi method (Hart et al., 2009)
Appendix 9: Technology Readiness Levels (TRLs) descriptions

- **TRL 1** – basic principles observed: Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
- **TRL 2** – technology concept formulated: Once basic principles are observed; practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions.
- **TRL 3** – experimental proof of concept; Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology.
- **TRL 4** – technology validated in lab: Basic technological components are integrated to establish that the pieces will work together.
- **TRL 5** – technology validated in relevant environment: Basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment.
- **TRL 6** – technology demonstrated in relevant environment: Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness.
➢ TRL 7 – system prototype demonstration in operational environment: Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.

➢ TRL 8 – system complete and qualified: Actual technology completed and qualified through test and demonstration.

➢ TRL 9 – actual system proven in operational environment: Technology proven through successful operations.
Appendix 10: TRL groups as defined by the OECD (Ekins & Salmons, 2010)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description of Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL 1-3 Basic Research</td>
<td>Activity driven by a desire to broaden scientific and technical knowledge, and is not explicitly linked to industrial or commercial objectives. It typically includes investigating the underlying foundations of phenomena and observable facts, and typically takes place almost entirely in the academic community.</td>
</tr>
<tr>
<td>TRL 3-5 Development</td>
<td>Research with a more direct commercial application, driven both by scientific enquiry (with a degree of public good in the outcomes) and commercial opportunity (with research areas driven by expertise in spotting market opportunity), and is seen as an opportunity to build and develop links between industry and academia increasing the likely success and pull through of ideas from the academic community.</td>
</tr>
<tr>
<td>TRL 6-7 Demonstration</td>
<td>Large-scale pre-commercial demonstration of technologies, designed to test and improve longer term operational reliability, develop and improve full scale designs, establish and reduce operating costs and take the technology to a stage where the technology becomes a potential commercial investment. Work is undertaken by the private sector, typically with some academic involvement.</td>
</tr>
<tr>
<td>TRL 8-9 Early deployment</td>
<td>Technologies have been shown to work on a large scale, but are not yet competitive in the market, require a policy and market framework that supports their deployment. Development is undertaken by companies in the private sector.</td>
</tr>
</tbody>
</table>

Appendix 11 Disposal options for municipal solid waste globally (Waste to Energy -WTE) (Hoornweg & Bhada-Tata, 2012).
Appendix 12: Estimated cost of impacts of marine litter on fisheries and extrapolation to EU fleet (Acoleyen et al., 2013)

<table>
<thead>
<tr>
<th>Cost of reduced catch revenue (trawlers)</th>
<th>Annual cost per vessel (€)</th>
<th># vessels in the EU</th>
<th>Total annual cost EU (m€)</th>
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<tr>
<td></td>
<td>2.340</td>
<td>12 238</td>
<td>28.64</td>
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</table>

<table>
<thead>
<tr>
<th>Cost of removing litter from fishing gear (trawlers)</th>
<th>Annual cost per vessel (€)</th>
<th># vessels in the EU</th>
<th>Total annual cost EU (m€)</th>
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<td></td>
<td>959</td>
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</table>

<table>
<thead>
<tr>
<th>Cost of broken gear &amp; fouled propellers</th>
<th>Annual cost per vessel (€)</th>
<th># vessels in the EU</th>
<th>Total annual cost EU (m€)</th>
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<tr>
<td></td>
<td>191</td>
<td>87 667</td>
<td>16.79</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost of rescue services</th>
<th>Annual cost per vessel (€)</th>
<th># vessels in the EU</th>
<th>Total annual cost EU (m€)</th>
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<tr>
<td></td>
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