Remediation of Marine Plastic Waste

Literature Review

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Plastics Production volumes have soared globally over the past 70 years. Rapid production and population growth coupled with inefficient waste management and plastic's slow degradation rate resulted in significant contamination of the environment. The World Ocean is becoming increasingly polluted with estimated 244 000 metric tons of plastics debris having reached the ocean since the 1950s. In our days, plastics waste is generated by almost every known economic sector at virtually each step of the product's lifecycle, leading to infinite possibilities for waste to become marine litter. Structured knowledge about sources, pathways, impacts and fate of plastics litter is essential for addressing the problem of marine pollution. This work is designed as literature review of a broad topic of plastics marine debris. The main goal is to collect information from multiple sources and condense accumulated knowledge into summaries related to plastics pollution. The fisrt chapter investigates the sources and pathways of marine debris. The next section investigates how plastics can pose a threat to the marine environment. The third section looks at ways of preventing marine pollution – at source, during lifecycle and after it becomes marine litter. Ways of reducing demand for pristine material and prolonging useful life of already existing objects are reviewed. The overall finding is that although scale of the problem is alarming, we have all the tools, knowledge and energy to minimize generated waste and change the trajectory of ocean pollution. For this to happen, effective upstream measures need to be taken such as improving waste management infrastructure, changing consumer behaviour, seeking sustainable material alternatives and thoughtful law enforcement. Unfortunately, the ocean will stay polluted for a long time as majority of the existing marine debris is submerged and can not be recovered in effective manner.

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List of Abbreviations

Abbreviation	Definition
ALDFG	Abandoned, lost or otherwise discarded fishing gear
HDPE	High density Polyethylene
MARPOL	Maritime pollution (The international convention for the prevention of pollution from ships)
MT	Million tons
Mt/y	Million tons per year
NAFTA	North American free trade agreement
OPR	Ocean plastic recovery
OPRV	Ocean plastic recovery vessel
PAH	Polyacrylic aromatic hydrocarbons
PCB	Polychlorinated biphenyl
PE	Polyethylene
PET	Polyethylene terephthalate
POP	Persistent organic pollutant
PP	Polypropylene
PVC	Polyvinyl-chloride
SDGs	Sustainable development goals
UNCLOS	United nations convention on the law of the sea
UV	Ultraviolet

1 INTRODUCTION

1.1 Overview

Water creates life. It is home to aquatic organisms, fuel for photosynthesis and a key element for respiratory processes of oxygen-dependent organisms. Water takes an active role in metabolism, plays a central part in the world's climate, and is an essential solvent in many biological processes.

Our planet is called Earth, although 71% of its surface is covered by water (Howard, 2016). Of all water, ~96.5% is concentrated in the World Ocean. Although the World Ocean is home to marine life and a key element to life on Earth in general, it is rarely thought of as a finite body of water with limited capabilities of self-restoration. Jacques-Yves Cousteau, the world's famous explorer of the seas comparable to Christopher Columbus, wrote following in his letter:

"*…we have deluded ourselves into thinking of the seas as enormous and indestructible. We have not considered that earth is a closed system. Once destroyed, the oceans can never be replaced. We are obliged now to face the fact that by using it as a universal sewer, we are severely over-taxing the ocean's powers of self-purification. The sea is the source of all life. If the sea did not exist, man would not exist. The sea is fragile and in danger. We must love and protect it if we hope to continue to exist ourselves*." (Cousteau, 1971)

Since 1970's the world has evolved drastically. The population has increased to over seven billion people, consumption and production levels have increased and the world became more interconnected socially and economically than ever before. Alongside the development of technologies and economy, humanity has started to have significant impact on the global environmental processes through overconsumption of natural resources, emissions and pollution of the environment.

One of the areas that has been rapidly developing in the past decades is plastics industry. It started off at about 5 MT/y in 1950s and has increased 60-fold by now (Geyer et al., 2017). Plastics industry uses about 4% of oil production as raw material and about the same amount is consumed as energy input in production. In theory, the industry can be very sustainable because the products can be recovered as material or energy but in reality, less than 10% of produced plastics is recycled worldwide.

The waste management system and legislation did not catch up with exponential growth of plastics production resulting in high volumes of plastic waste reaching the oceans (Hopewell et al., 2009). Typical plastics product's lifecycle is less than five years, but the lifespan can be over a hundred years, especially in marine environment. In order for plastics to degrade at a faster pace it requires UV radiation, high temperatures, presence of oxygen and abrasion. Due to the lack of proper conditions, marine plastics might take centuries to degrade completely.

Accumulation of plastics debris in the marine environment has adverse effects on marine biota and can have impact on entire eco-systems. It is often mistaken by marine species for food, which clogs up digestive tract and can lead to starvation and severely damage animal's health. Plastics also results in entanglement, which is presently the biggest threat for sea turtles and many marine mammals. In addition, it has potential to disrupt ecosystems through transfer of alien species and release of toxic additives. Finally, marine litter has also noticeable effects on people and economy. There are growing concerns for human health due to presence of microplastics in food and for decreased tourism in contaminated areas. (Li et al., 2016)

On the other hand, the world as we know it today would not be possible without plastics. Development in plastics have enabled huge breakthrough in medicine, potentially extending and saving millions of lives. Packaging made from plastics prolongs shelf life of food and requires lower amount of raw materials and energy for production as compared to paper, glass and metal alternatives. Plastics have relatively low weight-to-strength ratio, which enables to produce much lighter parts. In turn, transportation sector consumes less fuel and produces less emissions due to reduced vehicle and payload weight. Plastics materials such as foams are extensively used as heat insulation in buildings and construction, making houses a lot more energy efficient. This material is also integral part of electronics thanks to its insulation and semi-conduction properties.

Plastic as a material is neither good nor bad for the environment. It's a tool that brings versatile improvement possibilities to our life, but which can also make a huge damage to the environment if managed inappropriately on a global scale. In order to continue benefitting from this material, proper education, regulations and infrastructure need to be established that would enable sustainable production, mindful consumption and re-cycling. For that goal to be realized we need to have good understanding about sources, pathways and threats of marine pollution to take effective measures in mitigating pollution that is already happening and for developing sustainable plastics industry in the near future.

1.2 Objectives

The topic of marine plastics pollution is very broad with wealth of information accumulated on the problem over the past few decades. It is a global scale problem that has been receiving more and more publicity. As already stated above, in order to tackle the problem, proper background information is needed about various aspects of pollution – its origins, threats and methods to minimize waste generation as well as how to clean the environment from accumulated pollutants.

The main aim of this thesis work, therefore, is to give broad overview of the marine pollution situation. The first step of understanding the problem is investigating what has caused it in the first place. The first research question is then:

"What are the main sources of plastics waste and its pathways to becoming marine plastics debris?"

Marine plastics waste is rapidly accumulating in the oceans. It was found in very remote areas such as Antarctica and even deep on the Ocean's floor. The increasing presence of plastics in the marine environment inevitably affects marine biota and pose long-term threat to the world's eco-system. The second research question is then:

"*How does plastics debris affect Ocean's wildlife?*"

The final step is to learn about how to address the problem. There exist multiple ways to tackle littering both at source and at destination. Measures can be taken on organizational levels, such as reinforcing international or local legislation but at the end of the day global pollution to a large extent is a result of individual choices and behaviors. It is important to stop seeing plastics only as a convenience material but also to take into consideration its entire lifecycle, environmental footprint and ways to use it sustainably. The third question is then:

"*What are the existing preventive measures of plastics waste generation and how to mitigate already existing ocean contamination?*"

1.3 Work structure

This work is a literature study of several scientific articles, books and open use publications. The search for information was centered on topics of marine plastics pollution with emphasis on articles that would provide insight on the main research questions.

The first part and second part try to answer the questions about current volumes and sources of plastics waste generation. The third part looks for information about effects of species living in environment contaminated by plastics. The final part of literature review studies various ways of preventing and fighting marine pollution. Websites of clean-up organizations, start-up activities and news were visited to provide more recent information about progress in this area.

The collected information from literature review is condensed to summaries of the topics, including tables, to provide condensed overview of the findings about the researched questions. Suggestions are given bout where we are still lacking understanding and in which areas we have advanced a lot.

2 LITERATURE REVIEW

2.1 Plastic materials

2.1.1 Overview of plastics production

Plastic Materials or Plastics are a broad family of synthetic and semi-synthetic polymeric materials, typically derived from fossil fuels, that find applications in nearly all sectors of human life. They have gained popularity for their cost-effectiveness, easy manufacturing and unique properties that can be tailored to meet any product's requirements. For example, a designer can control melting point, color, chemical resistance, tensile strength, durability and conductivity of the material by choosing plastics type, additives, fillers and processing methods.

The plastics are usually divided into two categories: thermosets and thermoplastics. The thermoplastics have reversible characteristics, meaning the final product can undergo cycles of reheating, reshaping and cooling repeatedly. The thermosets undergo a chemical transformation when heated, meaning they create a three-dimensional network that does not melt upon reheating. Therefore, thermosets keep their initially attained shape until the end of a product's life. The two categories are presented in Figure 1.

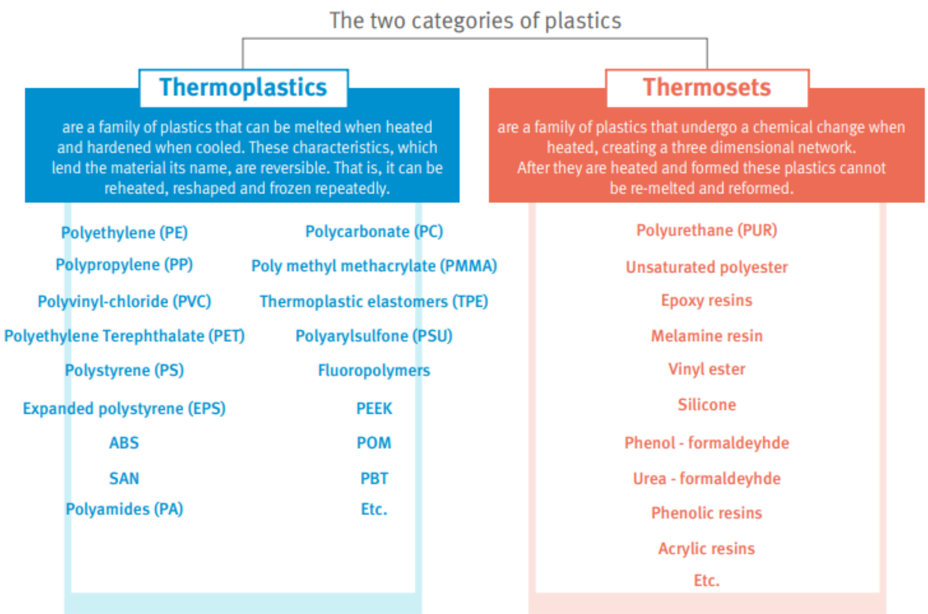

Figure 1. Common plastics types and their families. (PlasticsEurope, 2018)

As seen from Figure 2, the World's plastics production was experiencing an exponential growth starting from about 5 million tons per year (Mt/y) in 1950s and reaching an estimated 350 Mt/y in 2016, which cumulatively accounts for about 7.8 billion tons of plastics produced over the course of 70 years (Geyer et al., 2017). Figure 3 shows that for the currently estimated 350 Mt/y plastics production, about 50% is made in Asia, followed by Europe at 18.5% and NAFTA at 17.7% (PlasticsEurope, 2018).

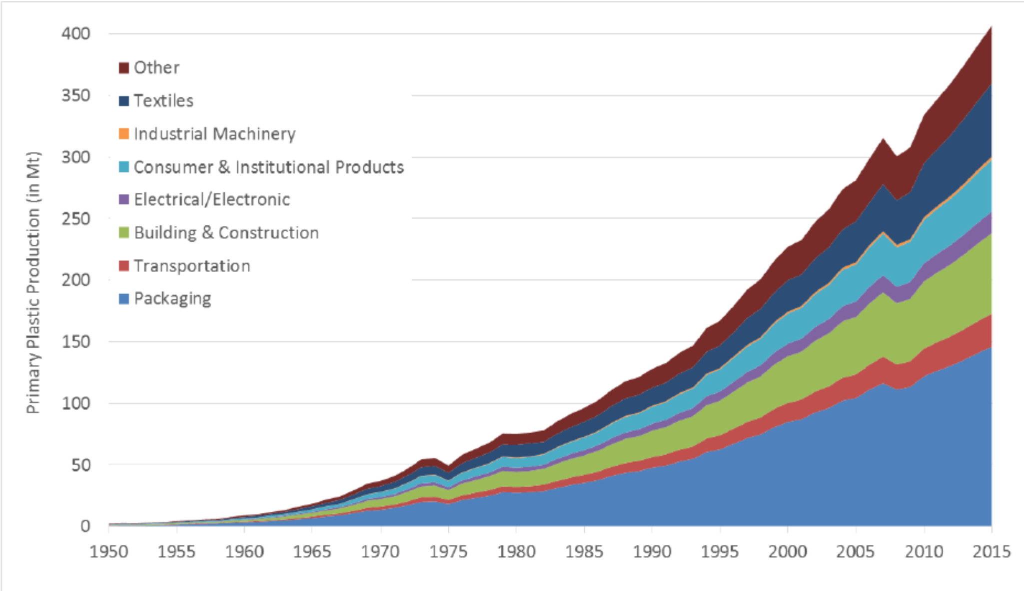

Figure 2. Growth of world's plastic production by sector type in MT between years 1950-2015. (Geyer et al., 2017)

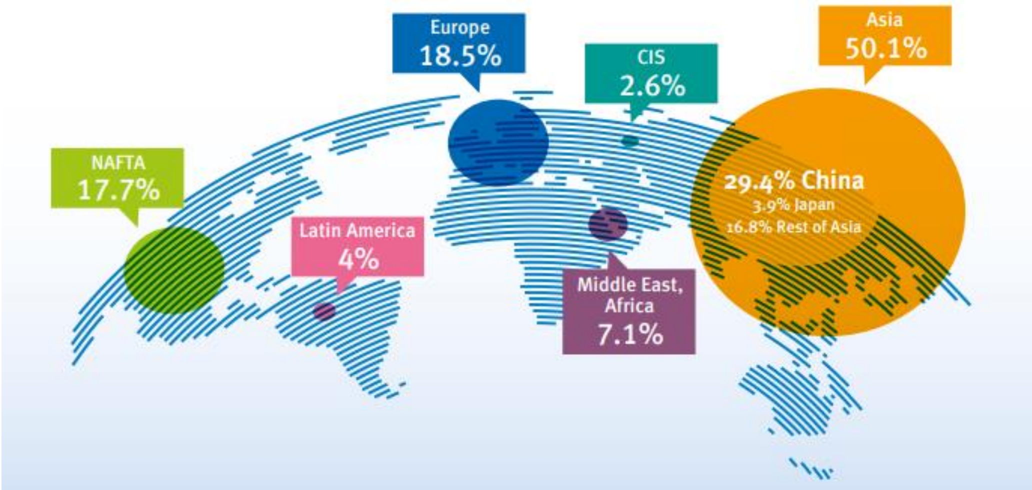

Figure 3. Distribution of global plastics production. (PlasticsEurope, 2018)

As is seen from Figure 2 and Figure 4, single-use plastics such as packaging, films, and disposable consumer items are the most produced category of plastics. It was observed that single-use disposable plastics amount to about 40% of production in Europe, 34 %

in NAFTA and 33% in China. The single-use plastics generally have very short product lifespan. For instance, Geyer et al. (2017) assumed that packaging materials go to waste in less than a year from production time and consumer products including textiles go to waste in less than 5 years.

Plastics with short lifecycles, such as packaging, gained their popularity for low cost, low weight, durability, health safety, and prolonged product shelf lives. On the other hand, the combination of high production volume, low value, and short life span create a threat of mismanaging plastics waste and leakage into the environment. Unfortunately, this is the case, and single-use plastics were found to constitute 62% of garbage found in the waste streams in a study done by Consultic (2013).

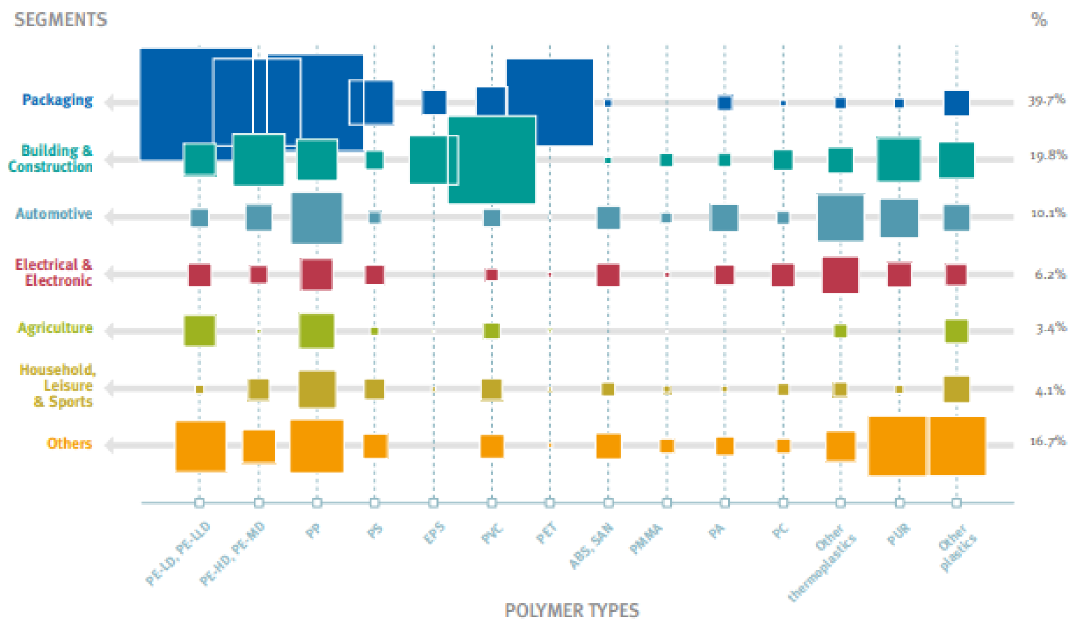

Figure 4. Demand for plastics by segment and polymer type; Packaging adds up to ~40% of EU plastics production. (PlasticsEurope, 2018)

2.2 Sources of plastic waste

First and foremost, plastic litter is a 100% result of anthropogenic activity. It does not occur naturally in the environment, and it is not produced by other living organisms. Analysis of human activities that are leading to waste generation is vital for the planning of responses to littering on personal, local and international levels.

Stefatos et al. (1999) identified in their study that plastic garbage was the most common pollutant found in marine debris. They suggested that major sources of marine debris might be on land, and it could be transported into the seas by winds, rivers, and streams. It was later estimated that land-based sources of plastic debris contribute about 80% of the plastic input to the marine environment, and ocean-based sources contribute the remaining 20% (Derraik, 2002; Li et al., 2016). However, the 80/20% proportion should be used with caution as it is linked to the most common plastic litter found on the beaches during clean-up campaigns, while the actual proportions vary depending on the remoteness of the sampling location, dominant human activities in that area and method of classification of the collected items. (Jambeck et al., 2015; Joan et al., 2016; Li et al., 2016)

2.2.1 Macro- and microplastics

The plastics waste in the environment is subdivided into two main groups of macroplastics and microplastics. The macroplastics are all the plastics objects larger than approximately 5 mm in size. This category of plastics waste has been widely acknowledged already since the 1990s and subjected to numerous studies and publicity over the past 30 years. (Li et al., 2016)

The term “microplastics” was coined for the first time in 2004, but there is still no universal agreement about the full definition of the term among researchers. For example, microplastics are sometimes subdivided into primary and tertiary microplastics. The primary microplastics are produced specifically to be of microscopic dimensions, such as pellets, plastics microbeads used in personal care, capsules etc. Some researchers may include wearing of tires, textiles, road markings, and hull coatings into the category of primary plastics. The tertiary microplastics are produced through fragmentation and degradation processes under environmental factors. Tertiary plastics are therefore being constantly released into the marine environment under the action of sunlight, atmosphere, water, and mechanical abrasion. Additionally, a term of nano plastics was recently proposed to define plastics particles with dimensions between 1 nm and 1 μm. (Frias and Nash, 2019)

The latest suggestion for the definition of microplastics was proposed by Frias and Nash (2019):

"*Microplastics are any synthetic solid particle or polymeric matrix, with regular or irregular shape and with size ranging from 1 μm to 5 mm, of either primary or secondary manufacturing origin, which are insoluble in water*". (Frias and Nash, 2019)

2.2.2 Ocean-based sources

One major contribution to pollution is through ocean-based activities. For example, Horsman (1982) estimated that 639,000 plastic packaging containers were dumped from world's fleet into the waters each day; and sinking of the fishing fleet in 1975 accounts for about 150 000 tons of plastics fishing gear and packaging released into the oceans (Li et al., 2016). Unfortunately, there is a considerable time gap in studies for ship-generated waste, which makes it difficult to estimate global inputs of plastics from ocean-based activities. Joan et al. (2016) claim that the latest global estimate for ship-generated waste, that would include fishing fleet, commercial vessels, and passenger ships, was produced 43 years ago, or back in 1975.

Notably, MARPOL Annex V (The International Convention for the Prevention of Pollution from Ships), which set up tight regulations on throwing garbage, including plastics items, was ratified in year 1988. This resolution has changed the way how the majority of commercial fleet behaves, potentially making global statistics gathered prior to 1988 inaccurate for extrapolation into present days. (IMO, 1995)

One of the large sources of marine plastics comes from the fishing fleet and aquacultures. This source of plastics waste is sometimes referred to as "abandoned, lost or otherwise discarded fishing gear" (ALDFG). Good et al. (2010) estimated that the amount of fishing gear lost to the environment has quadrupled over the past 30 years. About 640,000 t/year of fishing gear ends up in the ocean adding up to about 10% of the yearly marine debris input, and there is currently no systematic way for controlling fishery vessels. The discarded gear from the fishing fleet mainly consists of nylon fishing lines, fishing nets, and plastic packaging. Although at a much smaller scale as compared to fisheries, objects such as ropes, caging and polystyrene buoys are released from aquaculture activities such as mussel and salmon farms. (Joan et al., 2016)

The shipping industry, although being heavily regulated by MARPOL, can still be an important source of marine litter. On average, per million transported containers 14 are lost at sea due to harsh weather. First of all, it is clearly seen from Figure 5 that world trade through the containership fleet is 18 times bigger than 40 years ago (Statistica, 2019). In the year 2017 about 1834 million tons of goods were shipped with containers. Assuming standard 40 ft containers (capacity of 27.6 tons) loaded on average to 80% capacity, containing 10% plastics goods yield about 116 plastics containers lost per year. This is approximately equal to 3000 tonnes of plastic. A similar calculation, although yielding 4000 tonnes of plastic is presented in (Joan et al., 2016).

$$\frac{1834 \times 10^6\, t}{27.6 \times 0.8\, t/container} \times 0.1(plastic) \times \frac{14}{10^6}(lost) = 116\ lost\ plastic\ containers$$

On top of the obviously large losses from containers, merchant fleet can contribute to the problem through unintentional littering such as wear of hull coating, lost gear and securing equipment and large amounts of plastics (films, straps, bags, pellets) being used in everyday logistics operations. A lot of activities are carried out in harbors and shipyards, where waste handling depends largely on local waste management infrastructure and can potentially become large sources of waste.

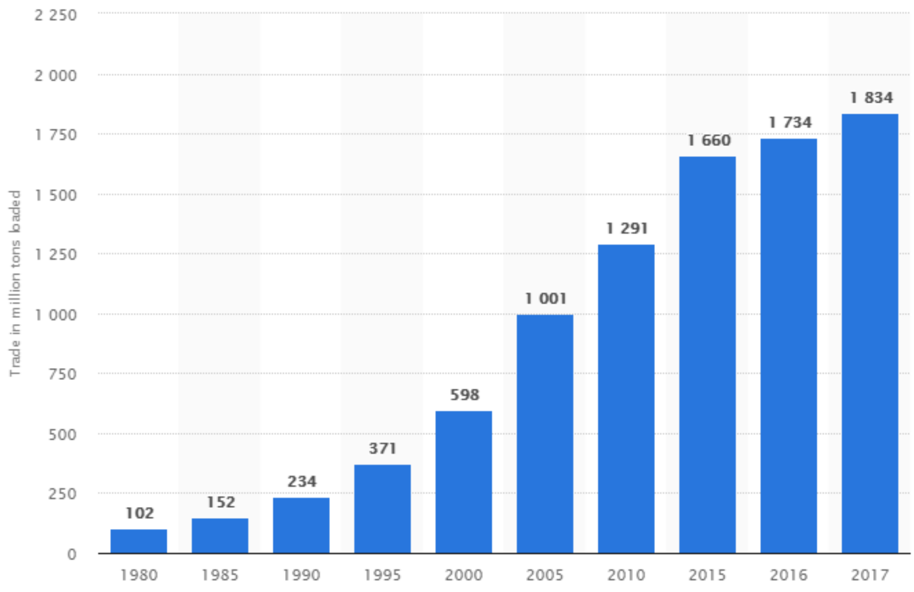

Figure 5. International trade in million tons carried by container ships (Statistica, 2019)

2.2.3 Land-based sources

In a model developed by Jambeck et al. (2015), approximately 8 million tons (MT) of plastics reach the seas and oceans from populated areas within 50 km of the shoreline. In the model, population size, industrialization, and quality of waste management systems were the main factors contributing to marine pollution. Table 1 based on data from Jambeck et al. (2015) also shows that countries with high population near the shores and poor waste management systems contribute the most to the accumulation of plastics marine debris. The same information from Jambeck et al. (2015) was visualized on top of the world map by Joan et al. (2016) and can be seen in Figure 6.

Table 1. Countries contributing the most to marine debris accumulation. Reproduced from (Jambeck et al., 2015)

Rank	Country	Population (million ppl)	Mismanaged Plastic (MT/Y)	The share of global mismanaged plastic (%)	Plastic marine debris (MT/Y)
1	China	262.9	8.82	27.7	1.32–3.53
2	Indonesia	187.2	3.22	10.1	0.48–1.29
3	Philippines	83.4	1.88	5.9	0.28–0.75
4	Vietnam	55.9	1.83	5.8	0.28–0.73
5	Sri Lanka	14.6	1.59	5.0	0.24–0.64
6	Thailand	26.0	1.03	3.2	0.15–0.41
7	Egypt	21.8	0.97	3.0	0.15–0.39
8	Malaysia	22.9	0.94	2.9	0.14–0.37
9	Nigeria	27.5	0.85	2.7	0.13–0.34
10	Bangladesh	70.9	0.79	2.5	0.12–0.31
11	South Africa	12.9	0.63	2.0	0.09–0.25
12	India	187.5	0.60	1.9	0.09–0.24
13	Algeria	16.6	0.52	1.6	0.08–0.21
14	Turkey	34.0	0.49	1.5	0.07–0.19
15	Pakistan	14.6	0.48	1.5	0.07–0.19
16	Brazil	74.7	0.47	1.5	0.07–0.19
17	Burma	19.0	0.46	1.4	0.07–0.18
18	Morocco	17.3	0.31	1.0	0.05–0.12
19	North Korea	17.3	0.30	1.0	0.05–0.12
20	USA	112.9	0.28	0.9	0.04–0.11

In terms of sectors responsible for land-based plastic waste generation and transportation, the situation is rather intricate. Plastics are so widespread that literally, all industries make use of it. The plastic product's lifecycle typically includes transportation of raw material, manufacturing, distribution to businesses or to retailers, consumption, and disposal. Along each step, there is a potential for plastic waste generation.

In the plastics industry, raw plastics materials such as pellets are sometimes spilled during transportation and handling. The logistics of the pellets are complicated, involving multiple packaging, delivery and handling operations (Redford et al., 1997). According to Derraik (2002), plastic pellets are found in abundance, over 100 000 pcs/m^2 on the coasts of New Zealand, and in especially high concentrations near industrial centers.

After the production stage, plastics are transported to retailers or businesses for further use. The global estimate on plastics produced and plastics waste generated by different sectors is shown in Table 2. The table statistics are comparable to information presented for EU countries in Figure 4.

Table 2. Plastic production and waste generation by sector in 2015; adapted from (Geyer et al., 2017)

Market Sector	2015 Primary Production (Mt)	2015 Primary Waste Generation (Mt)
Packaging	146	141
Transportation	27	17
Building and Construction	65	13
Electrical/ Electronic	18	13
Consumer Products	42	37
Industrial Machinery	3	1
Textiles	59	42
Other	47	38
Total	407	302

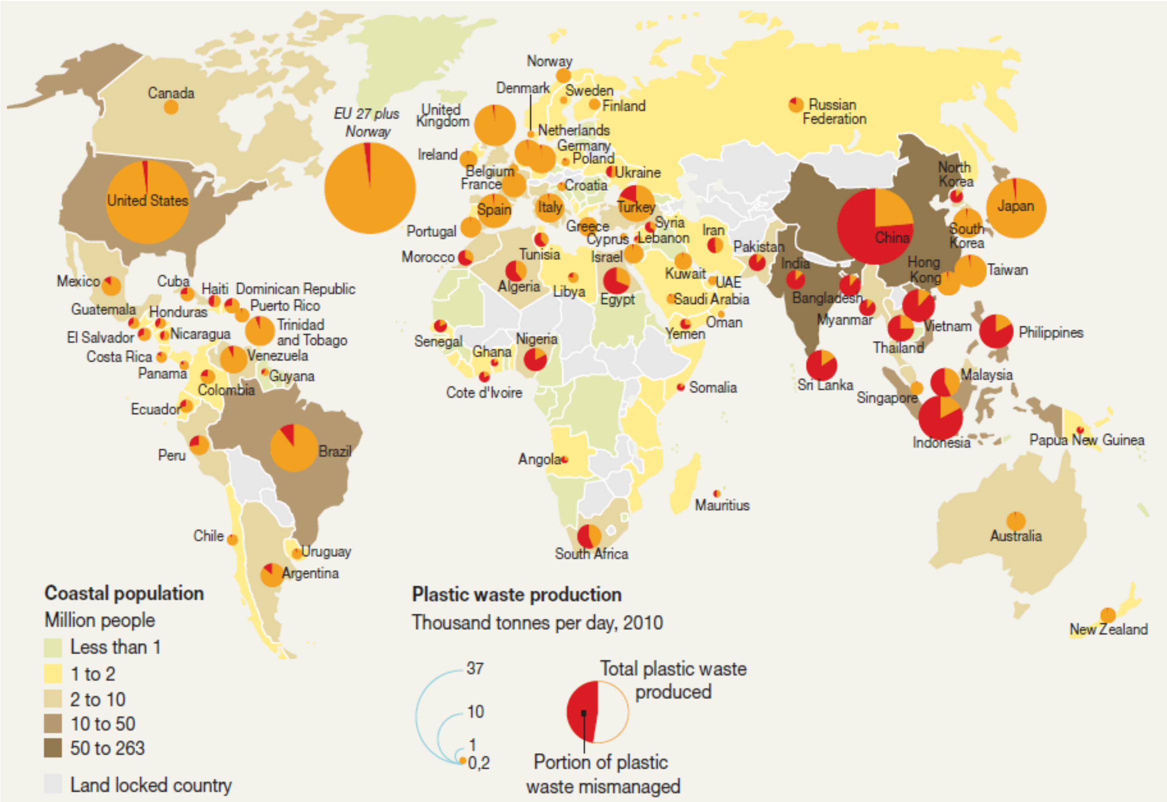

Figure 6. Plastic waste produced and mismanaged in the coastal areas. Graphics from (Joan et al., 2016); based on (Jambeck et al., 2015)

Generated waste by mass is noticeably lower than produced plastics, especially in categories such as construction and transportation because some products' lifecycles are generally longer than a year (Geyer et al., 2017). Eventually, most of the generated waste is being disposed of – that is, it reaches a solid waste management system.

Waste management infrastructure involves a number of procedures that vary depending on location and implementation. In general, it involves planning of distribution of disposal bins, collection and transportation logistics, proper processing and disposal of materials. For example, lack of disposal bins near houses or lack of waste storage spaces on production sites typically results in improper disposal of litter, which is harder and costlier to collect. Transportation of waste in e.g. open-top trucks can result in some waste being blown off or large waste spills in road traffic accidents.

The waste processing facilities themselves play an important role in litter accumulation. Simple dumping of materials on landfills does not remove plastics from the environment, it just creates accumulation hotspots. Such cases are referred to as inadequately disposed waste as plastics can be easily blown off from the landfills by gusts of wind, birds or carried away with water in case of flooding events. A more thorough processing followed by incineration or recycling is a better way of plastic waste handling as it preserves the environment from contamination and saves raw materials. The share of mismanaged or inadequately disposed waste is shown for many countries in Figure 6, where the size of the circle is proportional to the amount of generated plastic waste. The colored red segment of the circle shows the share of mismanaged waste (Jambeck et al., 2015).

End consumers play a very important role in plastic waste generation. First of all, people are prone to littering, intentionally or unintentionally. An example of intentional littering is throwing away cigarette butts, plastic cups and bags instead of disposing of them in appropriate locations. In the case of unintentional littering, people are simply not aware that, for instance, flushed cotton buds or wrappers can pass through municipal sewage systems and end up in the river streams.

Here, the level of an individual's awareness about pollution plays an important role in the amount of littering. A person can choose to build healthy habits in themselves and generations that follow and incorporate recycling or at least proper disposal of waste into their daily routine. For that choice to take place, however, they need to be at least aware of the existence of the problem, its scale and how they can contribute to the solutions. There is currently no way of accurately measuring how much of plastics waste is being littered. Jambeck et al (2015), for example, assume that 2% of all generated plastics waste is originating from littering.

Furthermore, end consumers can consciously choose to pay more for more environmentally friendly packaging and stay away from plastics and other contaminating materials. Manufacturers and distributors nowadays try to minimize their waste and impact on the environment, but plastics remain economically optimal solution. More specifically, plastics are cheap, easy to mass-produce and compete well in mechanical and chemical properties with other materials. This generates a large volume of single-use plastic products such as wrapping, bags, and packaging. If consumers would mindfully shift towards, perhaps more expensive material solutions, the overall volume of plastics production would decline together with the decline in demand for such products.

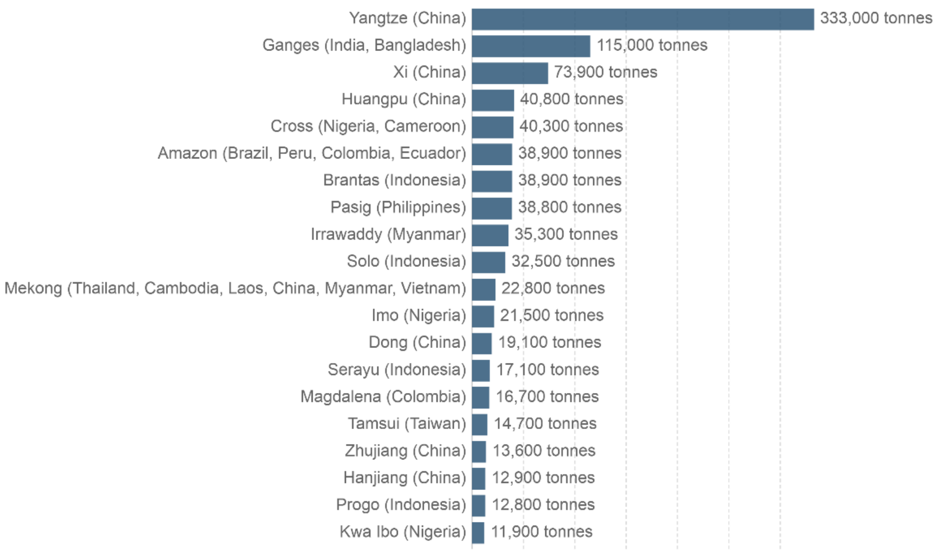

Figure 7. Plastics input to the ocean from the top 20 polluting rivers around the world. Sorted by name, location, and mass of waste transported. Created by (Ritchie and Roser, 2019), Source of information from (Lebreton et al., 2017)

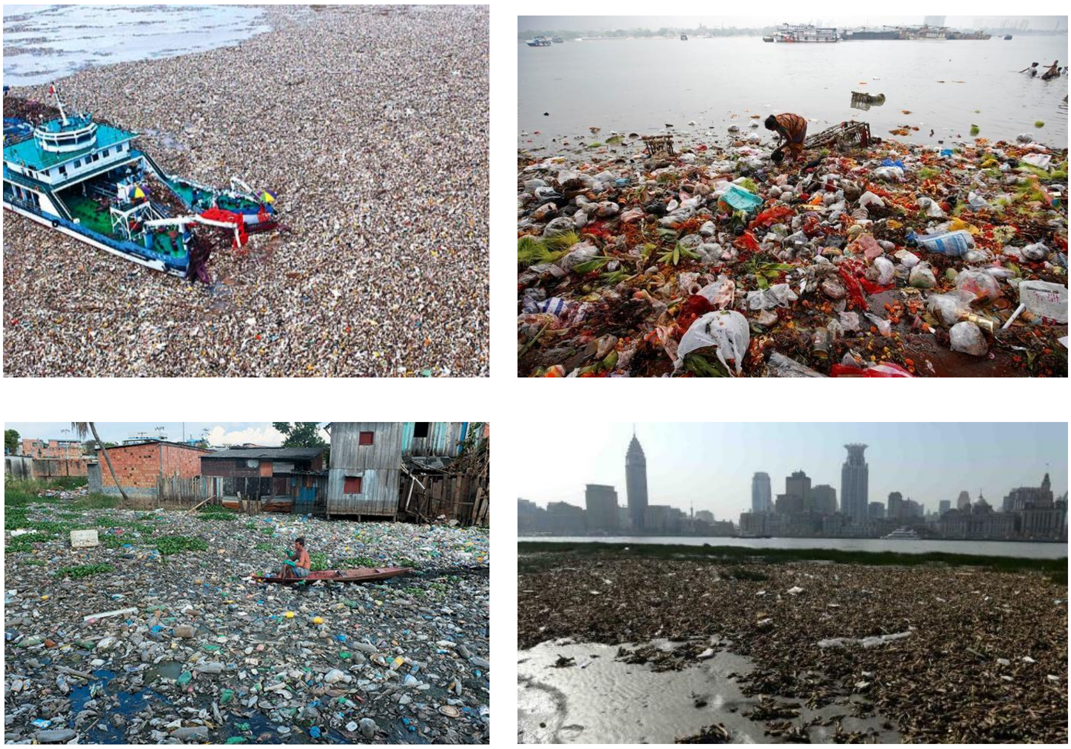

Figure 8. Pictures of the selected rivers polluted with plastics waste. Top left: Yangtze river; Top right: Ganges river; Bottom left: Amazon river; Bottom right: Huangpu river

There are numerous pathways for how plastics reach the oceans. It can be caused by extreme or seasonal weather events such as hurricanes and flooding. The more natural way, though, is through rivers, streams, municipal sewage systems and recreational activities near the shoreline. Rivers are especially important in plastics waste transportation to the oceans as they can carry objects from very far inland. For example, Lebreton et al. (2017) have developed a global model of plastics waste transfer through rivers. They concluded that rivers carry about 1.15-2.41 MT of plastics per year. Most of the waste is carried by rivers found in Asia (86%), followed by Africa (7.8%) and South America (4.8%). The top 20 polluting rivers are shown in Figure 7 and pictures of some of the selected rivers are shown in Figure 8. (Lebreton et al., 2017)

2.3 Impact of plastics on ocean's eco-system

2.3.1 Accumulation of plastics in the ocean

As estimated in the model developed by Jambeck et al. (2015), between 4.8 and 12.7 MT of plastics garbage reached oceans in 2010 from within 50 km of coastline of the 192 countries considered. According to the same model, depending on how many improvements are made to the waste management in coming years, a total input of plastic waste from 2010 till 2025 into the oceans will be between 100 and 250 MT.

There is no universal agreement on how long exactly plastics require to fully decompose, as its mass production started less than 70 years ago and there is no empirical evidence to support any claims. Still, it is a common assumption that all of the plastics produced, except for a share that was incinerated, is still in use or present in the environment as whole pieces or fragments. Plastic fragments, however small they might be, are still considered as plastics particles and have negative effects on the marine environment. (Thompson et al., 2009)

Fragmentation, a process of polymer object breaking down into smaller polymer fragments, happens under influence of UV radiation, physical abrasion and, to a lesser extent, from the chemical interaction of plastics with water and atmosphere (Andrady et al., 1993). For example, it is easy to find plastic items that are severely fragmented from continuous friction against sand and exposure to sunlight on the shorelines. Decomposition, on the other hand, happens when the molecular chain is broken – for instance during incineration. Therefore, fragmentation increases the number of smaller plastics particles floating in the ocean but does not necessarily lead to full decomposition into natural chemical components such as methane, carbon dioxide or other non-synthetic molecules. (Hopewell et al., 2009)

A large share of the produced plastics has a lower density than seawater (~$1.025\ g/cm^3$), which means they float and can easily be transported with winds and sea currents around the ocean. The large scale geographical distribution of plastics waste strongly depends on the entry locations, type of plastics and prevailing waves, winds and currents (Edyvane et al., 2004).

After reaching the marine environment, plastics can sink to the bottom, get trapped at the entry point or continue drifting around the ocean carried by winds and currents. The surface currents in the ocean are typically driven by winds, hence they resemble long-term wind patterns. Some currents, also referred to as gyres, are closed-loop and circular, meaning that once the object reaches the gyre, it is trapped in there for a while. As plastics can drift in waters for decades, many reach the gyres resulting in areas of high waste concentrations around the ocean. There are five large gyres in the ocean – North Atlantic, South Atlantic, North Pacific, South Pacific, and Indian Ocean gyres – with estimated about 5 trillion plastic pieces being afloat in the entire ocean according to Eriksen et al. (2014), (see Figure 9).

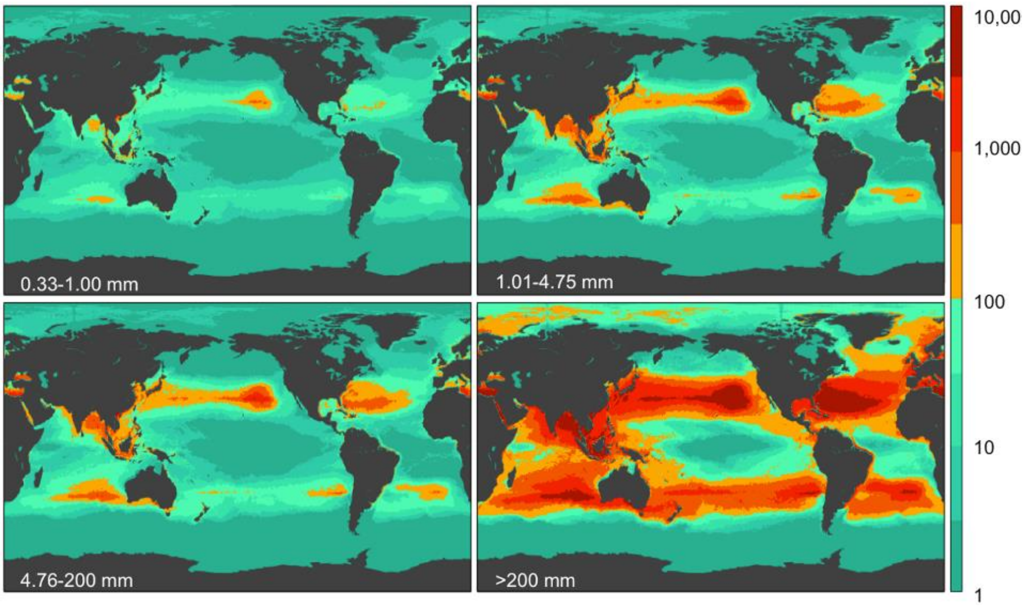

Figure 9. Oceans with the highest concentration of plastic shown in dark red subdivided into four size groups; Image by Eriksen et al. (2014)

Although the amount of plastics floating on the sea surface is high, researchers suggest even larger amounts of plastics items trapped in the water columns or on the seabed. For example, a survey of Great Pacific gyre showed that majority of collected surface plastics by weight was macroplastics (~85%) and a smaller than expected proportion of microplastics (Eriksen et al., 2014). Another study by Zettler et al. (2013) shows that the majority of plastics particles collected from waters were from positively buoyant and very common packaging materials – PP and PE. Although there is no accurate way of measuring the total amount of debris in the waters, an estimate drawn by Joan et al. (2016), which was based on an extensive literature survey, shows that plastics floating on the surface account only for 1% of plastics in the oceans.

There are several proposed explanations for "missing" plastics. Some plastics are negatively buoyant, meaning once discarded, they will sink. Large amounts of negatively buoyant plastics can enter waters, especially in populated areas, from the coasts, recreational activities, and ships. The negatively buoyant plastics that reach coastal waters are deposited on the sediment and moved further into the seas by tidal waves and currents. Some closed volume plastics like bottles can remain buoyant and drift on the surface until their cavity is filled with water, leading to eventual sinking to the seafloor. The plastics lost by fishing fleet, for example negatively buoyant Nylon nets, also sink to the seafloor or get trapped in the water column. Studies of seabed done by Pham et al. (2014) show macroplastics debris almost everywhere in the oceans with concentrations of ~100-300 pcs/km^2 in shelf areas, ~200-600 pcs/km^2 on continental slopes and ridges, ~ 400-700 pcs/km^2 on submarine mounds and banks, and 600-1200 pcs/km^2 in submarine canyons.

Study of deep-sea waters (1000-3500 m deep) sediments in different locations around the world done by Woodall et al. (2014) revealed high concentrations of microplastics, especially of acrylic and polyester microfibers. The concentration of microfibers in sediments, on average 4000 pcs/m^2, were about four orders of magnitude larger than those documented in surface waters in plastics gyres. A conservative extrapolation of the above resulted in 4 billions of fibers per km^2. (Zalasiewicz et al., 2016)

Acrylic and polyester are denser than seawater, so they are most likely behaving like feathers in the air – slowly drifting with currents through water columns until they reach the sediment. This means they can easily be transported around the ocean and slowly accumulate at the sea bottom. In addition to dense polymers, positively buoyant plastics were observed in the sediments. It is proposed that microplastics gain density through biological processes. For instance, those could be consumed by organisms and sink to the seabed with feces. In another process, plastics particles as they get smaller get higher and higher surface to volume ratio, which coupled with contamination by living organisms causes density change of the fragments and eventual sinking to the seafloor. Figure 10 shows possible pathways for transportation and accumulation of plastics on the seabed. (Joan et al., 2016; Zalasiewicz et al., 2016)

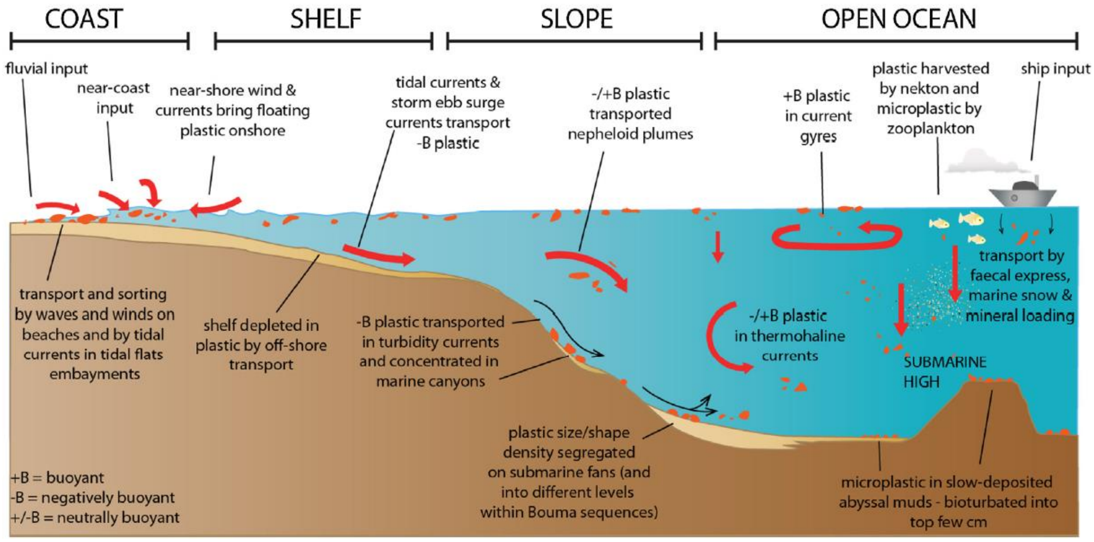

Figure 10. A model of transportation and accumulation of plastics objects on the surface, water column and in sediments (Zalasiewicz et al., 2016)

2.3.2 Ingestion by species

Accumulation of plastics in the oceans has a negative impact on marine biota. All types of organisms feeding in waters: seabirds, all kinds of fish and marine mammals, have been observed to ingest plastic objects. The ingested plastic object provides an organism with no energy but provides a feeling of fullness. Plastics can get trapped in the digestive system for a long time, decreasing feeding stimuli, causing reproduction failures and, potentially, death of the organism. (Derraik, 2002)

Seabirds are well documented to ingest plastics during feeding and are potentially the most vulnerable species. Hard, undigested materials, such as plastics, usually stays in the tract, eventually leading to gastrointestinal blockage, starvation, and decrease in activity levels. It is a somewhat less critical case situation for fish and filter-feeding organisms, which can in most cases regurgitate the ingested plastics. (Li et al., 2016)

Size, color, and shape of plastic particles also matter. Animals target specific shapes and colors, mistaking it for potential prey. For example, turtles and various species of fish were documented to ingest primarily white and transparent plastics particles. For seabirds, there is a high variety of feeding techniques but many, especially juvenile birds, tend to mistake plastic pellets and lids for pray.

Larger fishes and predators are also ingesting large amounts of plastics. When they chase pray, they might ingest unwanted plastics debris during feeding. On top of that, they consume plastics that were already consumed by their prey. In this way, plastics can travel through the food chain and potentially end up on the human's plate. Figure 11 shows some pathways for how plastics can end up in the food-web. (Joan et al., 2016)

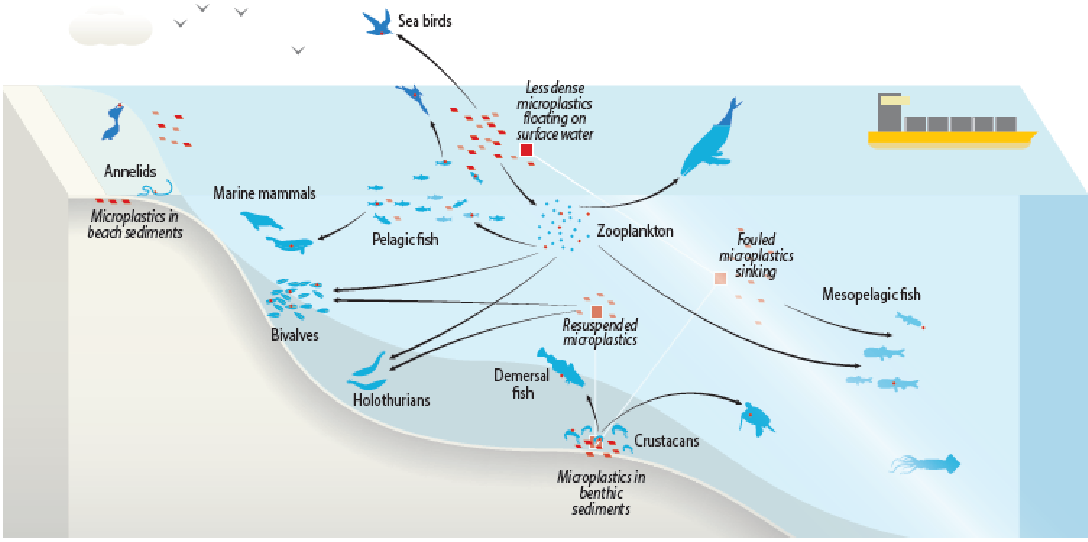

Figure 11. Examples of how and where plastics can be ingested by animals. (Joan et al., 2016)

2.3.3 Entanglement

The fishing gear discussed in Section 2.2.2 does not only accumulate as marine debris, but it also poses a big threat to the marine biota. Lost or discarded fishing nets take a long time to disintegrate in the marine environment and cause accidental entanglement of species or "ghost fishing". In a literature study of 340 publications by Gall and Thompson (2015), plastics accounted for 92% of the encounters between marine species and debris. Furthermore, the entanglement was a more common situation (55% occurrence or over 30 000 cases) than ingestion of plastics (34% occurrence). The entanglement cases were either more frequently reported or more serious as the harm caused to animals is direct, visible and often fatal. (Gall and Thompson, 2015)

Entanglement can potentially cause death through drowning, starvation, strangling, infection through cuts or through increased chances of being caught by other animals. For example, sea mammals such as seals and sea lions, especially young, are playful and curious. They are attracted to floating debris and get entangled as they start playing with. The net slips easily on the neck and the direction of hair growth prevents it from slipping off. It was noted by Derraik (2002) that for northern fur seals a small weight increase due to entanglement had caused a four-fold increase in food consumption to sustain daily activity levels. (Derraik, 2002)

Entanglement happens in different ways for other species. The two other most commonly entangled groups according to Gall and Thompson (2015) are sea turtles and sea birds. The sea turtles, for instance, are highly susceptible to "ghost fishing" because they tend to hide under floating objects for shelter or for hunting purposes. The sea birds can easily get caught in the netting while plunging into the water. (Li et al., 2016)

2.3.4 Transfer of alien species and toxins

Another important aspect of plastics pollution is its potential to alter entire ecosystems. Drifting plastics objects can become a habitat for many microorganisms such as bacteria and algae. The microorganisms are then transported beyond the areas of their natural habitats and introduced to the remote ecosystems, where those species are alien. Such cases of transfer of alien species are documented in Derraik (2002). Transfer of alien species is a dangerous case as ecosystems are fragile and the introduction of new unwanted species can seriously impair biodiversity.

In addition to accommodating alien species, plastics are said to absorb undissolved toxic substances from the surrounding waters. Li et al. (2016) noted that concentration of persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) or polyacrylic aromatic hydrocarbons (PAHs) can be a million fold higher in plastics than in the surrounding waters. Such pollutants are persistent in the environment, toxic, hydrophobic, and can bioaccumulate. When ingested by marine animals, the toxins accumulate in the organism and travel up the food chain.

Moreover, plastics themselves contain additives that can be leached into the marine environment over time while plastics objects degrade or bioaccumulate when ingested. Figure 12 shows a share of additives used in plastics production worldwide (Geyer et al., 2017).

Phthalates, for example, are widely used in PVC products as plasticizers to improve the material's flexibility and can constitute up to 30% of the plastic product by mass. Those chemicals are very common in building materials, cables, sealants, clothing, car parts, and textile prints. The plasticizers are not chemically bound to polymer matrix and therefore can leach out during degradation of the polymer. Phthalates have been reported to impair development and reproduction rates of several species. (Li et al., 2016)

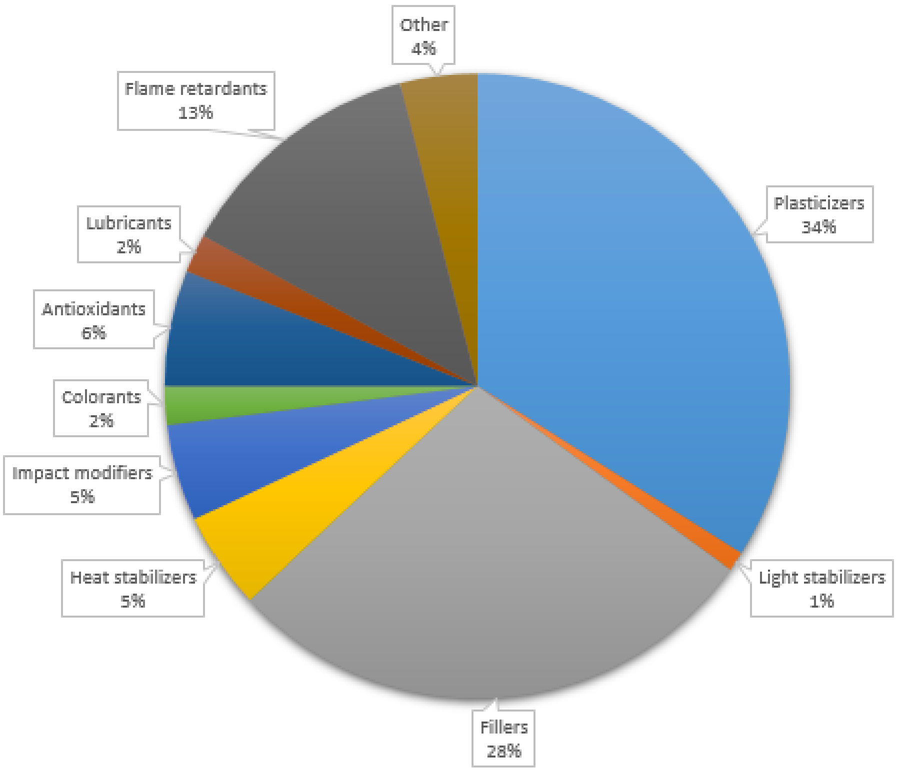

Figure 12. The share of additives used in plastics production worldwide. Rebuilt from statistics from Geyer et al. (2017).

3 MITIGATION OF MARINE POLLUTION

This section introduces possible pathways for reducing amount of waste that is entering the has reached the ocean or can potentially do so in the future. The section starts with brief introduction as to why ocean can not clean itself of plastics effectively and moves on to topics of manual clean ups and preventive measures.

3.1 Remediation of plastic waste

3.1.1 Natural remediation

As brought up in previous sections, degradation of plastics in marine environment is possible, but the process is extremely slow. The fragmentation rate of plastics objects is very much dependent on the surrounding environment (see Table 3).

Table 3. Environmental factors affecting degradation in marine environment. (Bergmann et al., 2015)

Environmental factors	Water surface	Sediment	Beach
Sunlight	Yes	No	Yes
Temperature	Medium	Low	High
Oxygen level	High/Medium	Low	High
Biofouling	Yes	Yes	No
Abrasion	Low	No	High

Photo-oxidation is among the most effective degradation mechanisms. It happens under influence of UV radiation that initiates free radical reaction in presence of oxygen. As a result of the reaction the oxygen incorporates into the molecule resulting in breakdown of polymer chains and decrease of the molecular weight. The wavelength has an effect on degradation rate – the lower it is, the more energy it has and, therefore, the more efficient it is in initiating a reaction.

It was mentioned by Bergmann et al. (2015) that considerable loss in mechanical strength happens already at low oxidation levels. This finding is important as weakened plastics leave entangled animals with a higher chance of surviving. As shown in Table

3, sunlight availability differs between beach, sea surface and seabed and the same is true for the surrounding temperature. Therefore, the plastic will degrade faster on a hot, sunny beach than on the ocean bottom, where sunlight never reaches.

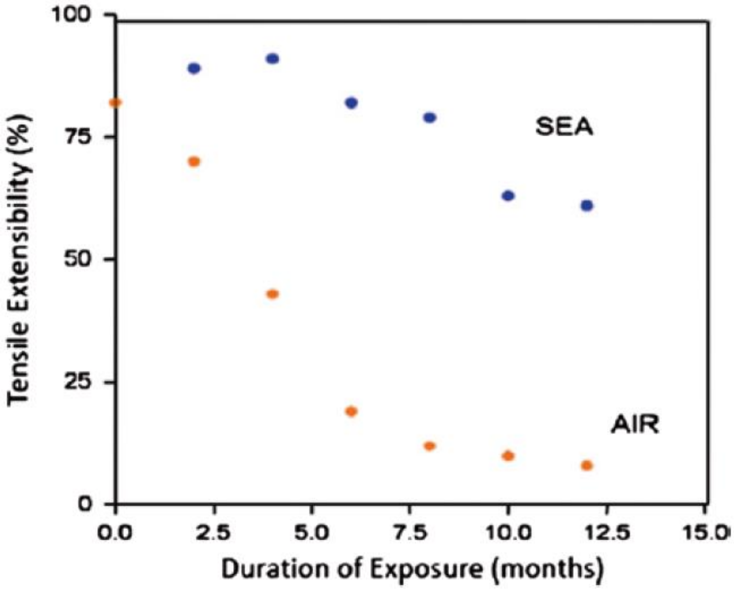

Figure 13. Change of tensile properties of plastic's samples exposed to sunlight in the air and in seawater near beach location. (Bergmann et al., 2015)

Figure 13, for example, shows a big difference in loss of tensile properties of plastics sample exposed to direct sunlight in air and one floating on water surface near the beach. In addition to environmental and location factors, color of plastic plays important role in degradation under UV exposure. Darker colored plastics consume more energy from sunlight and thus they degrade faster.

Mechanical degradation of plastics happens as a result of physical interaction of plastics object with surrounding environment. As seen from Table 3, the influence of mechanical degradation is mostly limited to surface waters and especially beach areas, where some movement and friction is possible. There winds and waves keep repeatedly pushing the plastics against the sand grains and, coupled with sunlight and heat accelerate fragmentation process. For the plastics items suspended in waters or laying on the sediment, on the other hand, there is not enough mechanical action to tear down or fatigue the polymer chains.

Biodegradation of plastics is a process of degradation under the influence of living organisms such as microbes, bacteria and fungi. In the first step of biodegradation process microorganisms adhere to the plastic surface. The process of microorganisms covering the plastics surface is called biofouling and the surface containing microorganisms is called biofilm. Biofilm changes plastics density and in some cases causes it to sink to the sea floor. This effect is especially pronounced for plastics with low volume and high surface area.

Although biofilm protects the plastic from UV radiation and therefore slows down the speed of degradation, it helps with the fragmentation process overtime. Some species of bacteria and fungi use carbon chains as a source of energy. They produce enzymes that are capable of degrading large polymer chains. Each type of plastic requires different types of microorganisms, and sometimes pretreatment, to start the biodegradation process.

When plastics are sufficiently fragmented, some types of bacteria can finish the degradation cycle by decomposing the polymer chains into simple compounds such as water and carbon dioxide. Little is known about spread of suitable microorganisms in the marine environment but so far researchers are skeptical regarding amounts of plastics that is being remediated in an uncontrolled environment.

3.1.2 Plastics recovery technologies

It was established that marine litter is a consequence of the mismanaged plastics, or a downstream problem. The most efficient way to tackle a problem is to fight with the cause and not the symptoms. As previously mentioned, majority of plastics in the oceans are not floating on the surface, so the recovery potential for submerged plastics is very low due to associated costs and technical limitations. Nevertheless, there are hotspots such as river mouths, beaches, bays and ocean gyres, where plastics can be reached and recovered relatively efficiently. Moreover, there is economic potential for recovery as recycled items can be sold and marketed as eco-friendly. The beach clean-up efforts are covered in section 3.1.3 and some of the selected plastics recovery technologies and teams behind the technologies are described in Chapter 4. (Joan et al., 2016)

For example, in section 2.2.3 rivers are estimated to carry about 1 MT of plastics per year into the ocean (Lebreton et al., 2017). Rivers are a perfect hot spot, where high plastics concentrations are present, flowing in a known direction and rather easily accessible from land. Several companies are looking into solutions to suspend trash in the upper layer of the river and direct its flow towards the traps, where it can be recovered in an efficient manner.

Other solutions look at collecting plastics in relatively calm areas such as ports or yacht clubs. Although those projects are small scale, they have a huge recovery potential if implemented globally. There also exist some large-scale project that aim at recovering plastics from the gyres directly in the ocean. Such initiatives have potential for recovering great amounts of floating materials that are already loose in the environment but in those are also costly and are yet to prove their effectiveness.

3.1.3 International beach clean-up activities

Apart from nature and technologies, plastics are collected all over the world on beaches by volunteers. One particularly big institution, Ocean Conservancy, has been organizing in collaboration with volunteering teams beach clean-up activities every year since 1986. By year 2016 around 11.5 million people have participated in the clean-up activities. In addition to clean up activities, volunteers document what type of litter was found and its quantity. Ocean Conservancy also partners with other organizations to identify most likely sources of found litter and to raise awareness campaigns that aim to alter consumer behavior causing littering. (“Ocean Conservancy,” 2017)

Figure 14 shows countries that participated in beach cleanup activities in year 2014. Approximately 46 countries took part in the international clean-up. Different shades of blue show the number of volunteers per 10 000 costal residents. As is seen, the most actively participating volunteers were in countries from North and South America, especially USA, Canada, Peru and Chili. This is likely due to the fact that Ocean Conservancy is originally from the US and is more known in that part of the world. Also, some island groups were particularly active in clean-up activities. Those islands are depending on tourism sector, which suffers from presence of litter on the beaches and in coastal waters. Keeping those areas clean is vital for local economy, tourism levels and fisheries.

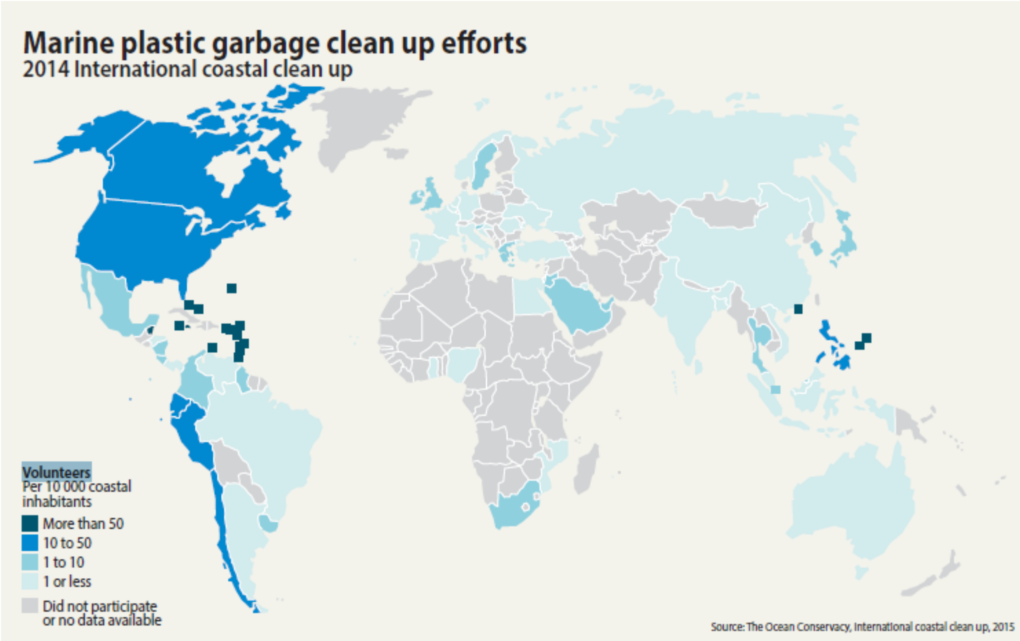

Figure 14. The Ocean Conservancy international clean-up map 2014

As already mentioned previously, volunteers document what type of litter they find. The collected data contributes to the largest and oldest database about beach litter. In addition, Ocean Conservancy has developed a phone app, CleanSwell, that can be used by anyone wishing to contribute to the cleaning efforts. People can download it and document any litter they have removed whenever they want to and wherever they are.

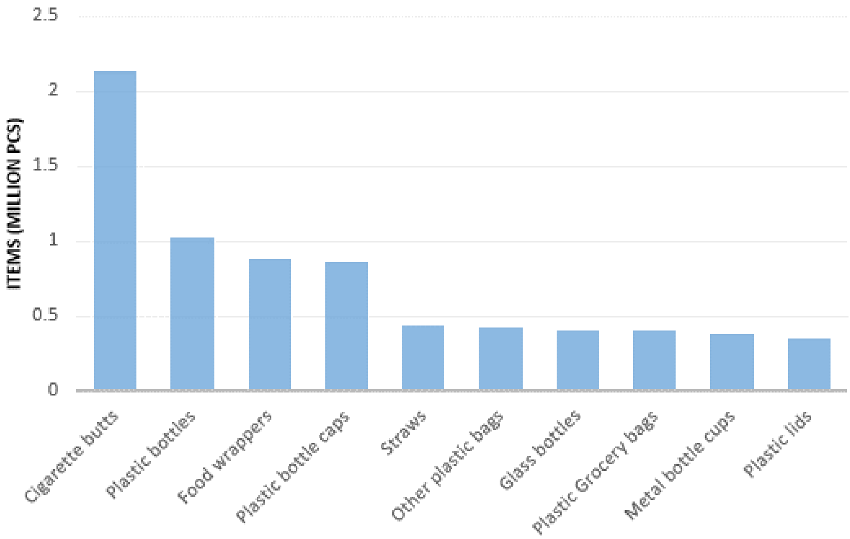

Figure 15. Top 10 worldwide litter found during beach clean-up activities in million pieces per category

According to collected statistics, the majority of the beach litter found globally is consumer products, especially single use plastics and packaging. The most common types of litter come from recreational activities, such as smoking, drinking and eating out. A list of 10 most commonly found litter is shown in Figure 15. Altogether, in year 2015 over 13.8 Million items were collected, which is over 8000 tons of garbage. According to Ocean Conservancy, a total of 95 254 tons of trash was collected within the past 30 years of activity. (“Ocean Conservancy,” 2017)

3.2 Prevention of marine pollution

3.2.1 Legislation

The problem of plastics pollution has not always been given the same amount of attention as nowadays. The mass production has started back in 1950s, and the prevailing opinion was that plastics will make life better and easier for everybody. The production rates took off rapidly reaching about 50 Mt/year by 1980s. It was during those years that first publications started to appear reporting impact of plastic debris on marine life. As is seen from Figure 16, legislation for plastics started to appear only in early 1990s. In this section, some of the most significant regulations and agreements related to production, use and disposal of plastics are introduced. (Zalasiewicz et al., 2016)

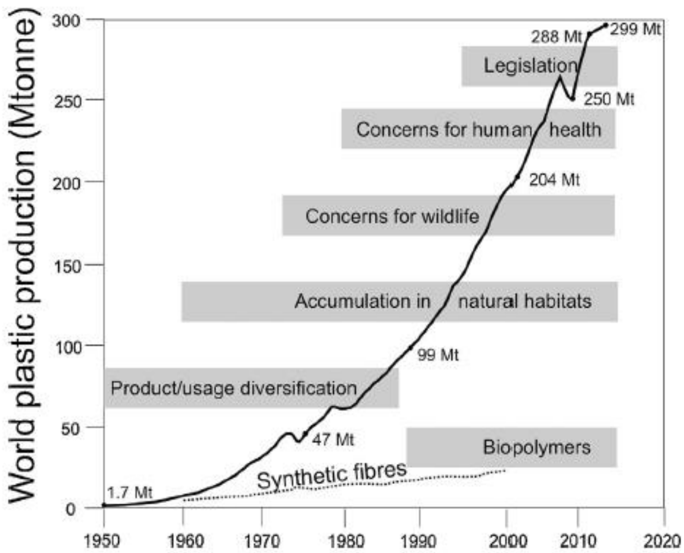

Figure 16. Historical growth of plastics production and of public awareness about the threats. (Zalasiewicz et al., 2016)

MARPOL 73/78 convention was already briefly mentioned in Section 2.2.2. It deals with pollution from ships by sewage and garbage, covering about 98% of world fleet by tonnage. In essence, MARPOL imposes a complete ban on disposal of any garbage into sea. Any ship above 400 GT (gross tonnes) or carrying over 15 people on board must provide a Garbage Record Book. There was a problem, however, that even if ships comply with MARPOL regulations, some ports might not have infrastructure to handle received garbage. Therefore, MARPOL also aims at improving port reception facilities and in general promotes environmental consciousness in the shipping industry. (IMO, 1995)

The London Convention (1975) or London Protocol (2006) aim to effectively control all sources of marine pollution including implementation of practical steps to minimize dumping of waste at sea. For example, the convention issued a gray- and blacklists for waste materials at sea. The gray list allows dumping of certain items if permission from authorities were given and all criteria were met. The black list on the other hand strictly prohibits any dumping of the listed materials. Recently, a discussion has started, where sewage and dredged materials might be added to blacklist as they are likely to contain some amounts of microplastics. (Joan et al., 2016)

SDGs (Sustainable Development Goals) is a roadmap to year 2030 planned by United Nations. The goal is to synchronize global, national and local initiatives related to sustainable development. The initiative addresses multiple pollution problems. Amongst them are waste management system, wastewater treatment, reduction of waste generation and prevention of marine pollution.

UNCLOS (United Nations Convention on the Law of the Sea) regulates activities carried out in oceans and seas including protection of marine environment from pollution. It regulates land based and sea-based pollution as well as pollution through atmosphere and seabed activities. For example, they see lost or discarded fishing gear as a serious threat to environment and propose methods for reducing its impacts on marine life and promote retrieval activities.

Regional seas conventions are regulations and action plans for countries sharing same waters. Practically every waterbody has some sort of regional regulation for mindful use of resource and prevention of pollution from sea and land. Also, there exist country and union specific policies. For example, European Union effectively regulates waste management, environmental protection and packaging production on its territory and has some influence on neighboring countries. One of the latest decisions is to ban single use plastics such as cotton buds, single use tableware, balloon sticks, stirrers and straws. In addition, the plan is to increase recycling of bottles to 90% and to put share of plastics collection costs on manufacturers, in particular manufacturers of common marine plastic waste such as of fishing gear and cigarettes. (Rachel Cooper, 2018)

Xanthos and Walker (2017) attempted to measure effects of market-based strategies such as imposing a ban, tax or levy on plastic products. This study in particular focuses on plastic bags and microbeads across the globe.

First of all, they noticed that problem of plastic bags was for the first time addressed globally in 1991 but number of interventions did not start rising till 2000s. There were no interventions for microbeads until year 2013. Another finding was that interventions are not synchronized across the globe and at times not even between adjacent municipalities. A major question arose about effectiveness of the introduced policies in various countries.

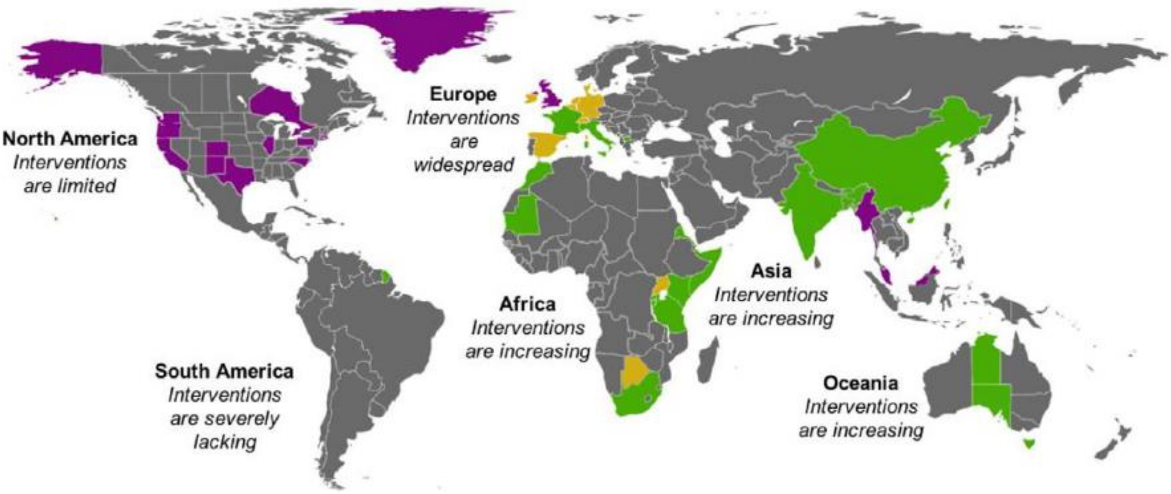

Figure 17. Bans on plastic bags around the world by year 2016. Green: full ban; Yellow: a tax on some type of bags; Purple: partial tax or ban. (Xanthos and Walker, 2017)

Xanthos and Walker (2017) came to conclusion that levies and bans on plastic bags are effective. For example, a small levy on plastic bags in Ireland led to 90% decrease in plastic bag use. A levy introduced in Wales had resulted in about 96% reduced plastic bag use within 5 years. Similar situation was observed for England, where levy on bags at major supermarkets resulted in about six billion fewer bags sold each year. In China bag consumption fell by about 60-80 % (about 40 billion less bags per year) after they banned bags thinner than 25 μm and put a fee on bags of other thicknesses. On the other hand, some countries found it difficult to enforce the law. In China, plastic bags are still commonly used by large amount of smaller shops and street vendors, which are hard to control. In South Africa the levy was too low and did not affect consumption of plastic bags.

The data about effects of microbeads bans is very limited. It is estimated that about 8 trillion pieces of microplastics enter the water streams due to cosmetics. Therefore, several countries are in the process of addressing this issue in present time. For instance, Netherlands and several other EU member states are requesting bans on microbeads within EU and discussing with manufacturers about voluntary abstinence from use of microplastics in their products. For example, the about 80% of Dutch cosmetic companies are free of microbeads as a result of cooperation with government. Unfortunately, for countries where microbead bans are in place, the effects of bans are not yet measurable. Mostly this is because bans were introduced recently and there is a delay between passing a law and implementing it. Also, most of the bans are implemented in phased approach to give time for manufacturers and retailers to adapt to upcoming changes. Last but not least, there is need for accurate methods for measuring effects of law enforcement, such as end op pipe testing for microbeads or collection of plastic bag data from shops and manufacturers.

3.2.2 Public awareness

Public awareness is societies’ level of understanding of the existence of the problem, its causes and consequences. The public awareness campaigns are there to advertise the problem through various media channels, education, events and activities. Nowadays there are numerous plastic pollution awareness campaigns around the world. This section is intended to introduce some of them.

Plastic Pollution Coalition is a worldwide alliance whose mission is to reach “a world free of plastic pollution and its toxic impacts on humans, animals, waterways and oceans, and the environment”. For example, the Coalition takes part in a viral antiplastic straw movement. They work with eateries to abstain from offering plastic straws with the drinks, encourage individuals to go “straw free” and spread the message further. In the grand scheme of things, they participate in such activities to shift perception of society on pollution caused by consumption and disposal of single-use plastics. (“Plastic Pollution Coalition,” 2019)

Another good examples of organizations that spread awareness are 4Ocean and Ocean Conservancy. 4Ocean engages local population and fleet in plastics recovery activities. By now, over 2000 tons of plastics have been recovered by 4Ocean employees paid through sale of their products. The main product, for example, is 4Ocean bracelet that is made from recycled glass and plastics. A purchase of such $20 bracelet pays for removal of 1 pound (0.45 kg) of marine litter. In addition to fighting marine litter one can help save coral reefs, dolphins, manatees, shark, sea turtles, whales, sea birds and other species by purchasing special edition bracelets. The other organization Ocean Conservancy organizes beach clean up activities with volunteers around the world and is involved with multiple organizations in organization of awareness campaigns and pollution statistics analysis. (“4Ocean,” 2019; “Ocean Conservancy,” 2017)

Rising public awareness about pollution and the need for sustainable production and consumption creates environmental values in consumer purchasing patterns. This forms a demand for eco-friendly products with recycled content, which intern encourages businesses and authorities to shift towards recycling and development of sustainable production. Below are a few examples of companies working to meet sustainability demands. (“Let’s reduce plastic in our Oceans,” 2018)

Fairy, a brand under UK company Procter & Gamble, launched 320 000 Ocean Plastic bottles in UK in 2018 to raise awareness about recycling significance and ocean pollution. The bottles were produced from 90% of post-consumer recycled plastics and 10% of ocean plastics. Apart from this single campaign, Procter & Gamble brands use 8 000 metric tons of plastic redirected from landfills per year.

Adidas in collaboration with Parley have created a few clothing and shoes collections using recycled ocean plastic throughout the past 2 years. Their mission is “to prevent plastic entering the ocean and transform it into high performance sportswear”. Since

2017 until now Adidas has launched trainers, football T-shorts, swimwear as well as yoga, tennis, running and rugby collections made partially from ocean plastic.

Saltwater brewery is a small brewery from Florida, USA, that has developed the first eco-friendly beverage six pack rings. The material is 100% biodegradable and edible for any species. When the ring is disposed of properly it takes only a few days to degrade completely. Improperly disposed ring is degraded in less than 200 days. By implementing this technology Saltwater brewery is trying to influence big beverage manufacturers and by their own example and contribute to the sustainable environment.

3.2.3 Waste handling strategies

Waste management are the activities required to address problem of waste materials. At its core, waste management involves collection, transport, processing and disposal of waste. In the modern day, there are several levels to the activities. The most basic management is through collection and disposal to landfill. The next level is processing of waste to yield energy, recover material, reduce waste volume and pollution or toxin release hazards. The novel approach, called "the 4R" – reduce, reuse, recycle and recover sees reduction of waste at source as a vital part of waste management strategies with landfills as a less desirable approach. This section outlines various options of handling waste – from control at source, through life-cycle and till end of life. (Hopewell et al., 2009)

Landfills

Landfills are the most common and the oldest waste handling methods around the world. The problem with landfills is that it rapidly accumulates a volume of waste until no more land is available and new landfill is needed. It works as a final destination in product's lifecycle and leaves limited possibilities for material recovery and reuse. Taking longevity of plastics in consideration, storing plastics in landfills only delays the problem for future generations. For instance, Zalasiewicz et al. (2016) states that up to several tens of meters containing plastic are uncovered at locations of old landfills that started working after 1950s. Plastics are already considered as a geological marker that could be used in far future to indicate 20^{th}-21^{st} century land deposits. Considering ever increasing amount of waste and lack of suitable lands in some countries, other methods of waste handling should be prioritized.

In short term, a well-established landfill eliminates pollution of the environment by solid waste. In the long term, however, there is a risk of contamination of soil and groundwater by toxic elements released through degradation of plastics and other materials. A poorly managed landfill can also result in waste blown by winds or carried by waters into the environment. Therefore, landfills score the lowest in waste management options but are still far better than direct littering.

Incineration and energy recovery

A less popular alternative to landfills is incineration. This method's advantage is that polymer chains degrade completely, reducing volume of waste and demand on the landfills with possibility to extract some energy. On the other hand, burning of plastics is dangerous for the environment due to release of hazardous substances into the atmosphere. This risk stops incineration from becoming more popular than landfills. The positive side of incineration is possibility of energy recovery for electricity, heating or direct use as fuel in blast furnaces. Incineration coupled with energy recovery saves natural resources that would otherwise be used to produce required heat or electricity.

Re-use of plastics items

Re-use of items, especially single use plastic items, can considerably extend product's lifespan and reduce both waste production and generation. The possibilities to do so at large scale are quite limited due to logistics issues. The product-filling factories are far from collection points and high variety of container designs and branding make it infeasible for collection and re-use. Some local businesses, however, have take-back and refilling schemes. For some more expensive product categories such as vehicle and electronic parts, re-use is a feasible scheme. Re-use is also popular for plastics used for transportation of goods such as pallets and bags. Finally, on the consumer level, some of the packaging, especially plastic bags, water bottles and food containers can be used several times and is a matter of habit rather than logistics.

Downgauging

Downgauging is a process of minimizing amount of material use per product, for instance in packaging. Minimization of material use results in minimization of waste generation. Although economically it is natural process for manufacturers since it leads to lower production costs, downgauging can significantly impact the way final product looks and sells. For example, a container from solid plastics can be replaced by sealed vacuum film, which is just as effective in increasing food's shelf time but is at least twice lighter. Downgauging is a perfect example of waste control at source. In the grand scheme of things, downgauging can have significant impact on total waste generation considering that packaging adds up to about 40% of plastic waste in many countries.

Recycling

Topic of plastics recycling is broad and complex in a sense that there exist multiple subcategories of recycling. The four main categories discussed here are primary, secondary, tertiary and quaternary recycling. The example rates of recycling and energy recovery (quaternary recycling) for EU countries are shown in Figure 18.

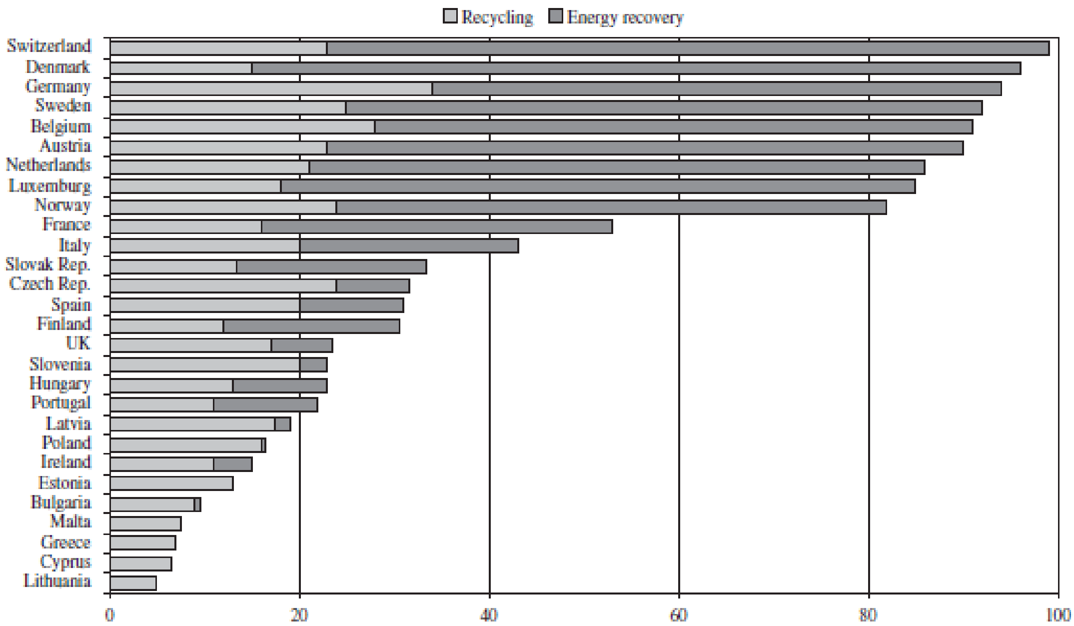

Figure 18. Plastics energy recovery and recycling rates in EU countries, shown as percentages of plastic waste management. (Hopewell et al., 2009)

The primary recycling is often called a closed-loop recycling because it is a full mechanical reprocessing into a new or same item with similar properties. Primary recycling is good for environment because it requires less energy and resources than making product from scratch as well as reduces waste generation.

Theoretically majority of thermoplastics can undergo close-loop recycling but alien materials such as metal, paper, colorants and adhesives complicate the process. In best case scenario, the plastic used for closed-loop recycling is clean of contaminants and is of almost the same grade to avoid instabilities during reprocessing. Clear PET bottles are the best example of closed-loop recycling product. They contain little contaminants and are all made from similar grades. Another example is recycling of HDPE bottles into HDPE crates and bins, where application of product changes after reprocessing.

A challenge with primary recycling lies also in logistics. Industrial plastic waste comes from few locations but in large volumes clean and sometimes sorted, which makes collection and reprocessing easy and economically feasible. Collection from consumers, on the other hand is much harder to achieve due to requirement to have return and collection schemes. Although per consumer volumes are low, total waste volume is about 5 times larger than from industrial sector, so there is clear need for improved collection and sorting schemes. Also, unlike for metals and glass, the polymer chains become shorter with each recycling cycle impacting material properties. Therefore, plastic item can undergo only a few closed-loop recycling cycles after which other recycling or disposal method needs to be used.

Secondary recycling, also referred to as downgrading is reprocessing into products that would not normally be done from virgin plastics. Plastic lumber, which can be extensively used for making benches, tables, fences and terraces is a great example of downgrading. Downgrading is an option for plastics that are not suitable for closed-loop recycling.

Tertiary recycling is de-polymerization of plastics to its chemical monomers. It can then be used to re-manufacture plastics, or to produce other synthetic products. Chemical recycling is more costly than production from petrochemical feedstock as it involves collection, treatment and energy input for decomposition. Therefore, this method is not often used unless serious subsidies are in place.

Finally, quaternary recycling is energy recovery from waste plastics. One option is incineration with waste heat or electricity recovery as described above. An alternative to incineration is pyrolysis for gasification and production of diesel fuel. Right now, this is a costly energy recovery option, but it might become more attractive in the long run as a result of rising fuel prices.

4 OCEAN CLEAN UP TECHNOLOGIES

This chapter gives an overview of the selected technologies that can potentially recover plastics from multiple locations such as rivers, bays and even open waters. The aim is to describe technical solutions, challenges and limitations of each technology.

4.1.1 Seabin project

The Seabin is a device that floats and collects garbage by pumping water through its filter. It is installed at the marinas, commercial ports, docks, and yacht clubs. For a proper functioning, the device requires calm water, mounting dock and source of electricity for the pump (see Figure 19). When the pump is activated, the Seabin starts to suck the surrounding water through a catch bag. The catch bag is filters out all the surrounding trash, including microplastics up to 2 mm in size, and releases cleaned water back into the bay. (Leonardi, 2018)

The Seabin is able to catch approximately 1.5 kg of trash per day and has total capacity to hold up to 20 kg of debris. The amount of caught debris varies with the pollution of the area. It is estimated by Seabin design team that it can capture the following amount of trash per year: 90,000 plastic bags, 35,700 disposable cups, 16,500 plastic bottles, 166,500 plastic utensils. (Leonardi, 2018)

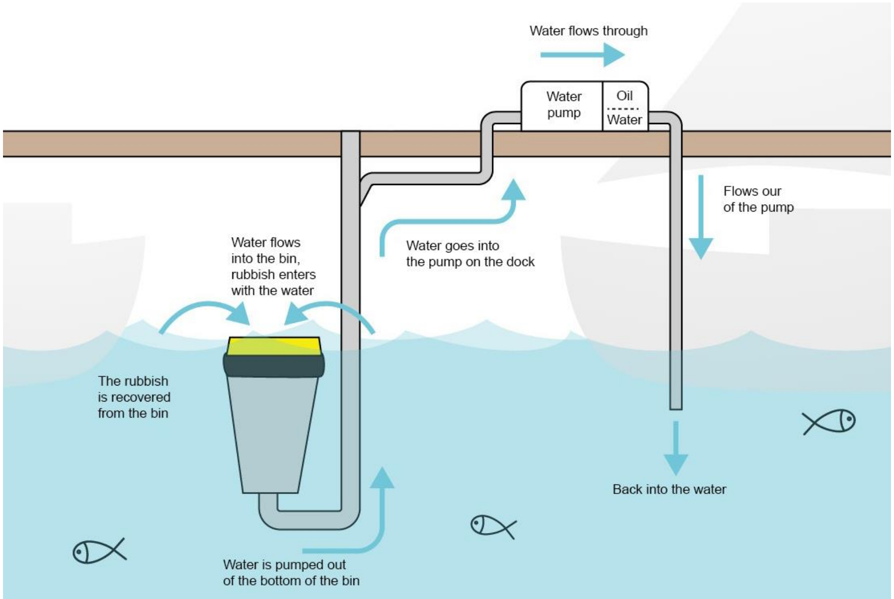

Figure 19. Work principle of the Seabin (Leonardi, 2018).

The Seabin project is currently working on a new catch bag with a special compartment at the bottom for microplastic and microfiber filter. Although the design is still not ready, the preliminary results are said to be encouraging.

4.1.2 The ocean cleanup

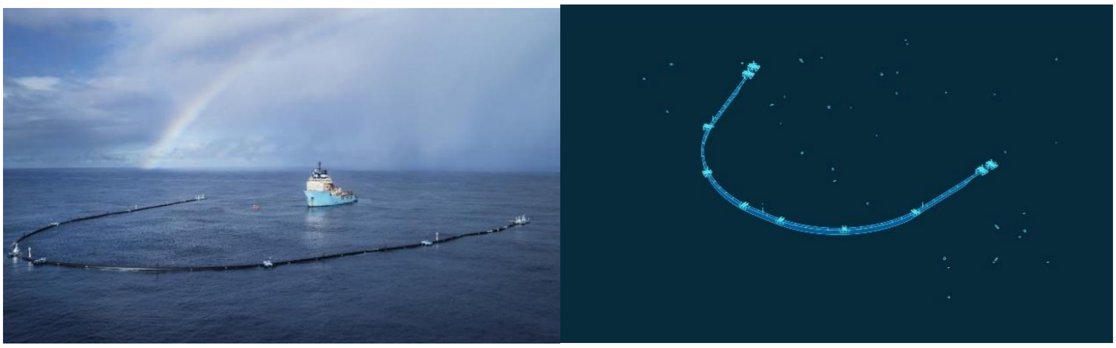

Figure 20. Drawing of The Ocean Cleanup system 001 ("The Ocean Cleanup," 2019)

The Ocean Cleanup has developed a system to collect marine debris from the gyres. The system is a large-scale device that is 600-meters long drifting on the water surface and powered by natural forces. It consists of positively buoyant booms that prevent plastic from flowing over it and a three-meter-deep skirt underneath that collects the plastic. The system was designed to capture only plastic material so marine life can pass safely through it. The floater is equipped with two satellite pods, two navigation pods, one camera pod, nine lanterns and over fifty sensors linked to solar-powered electronic pods. ("The Ocean Cleanup," 2019)

The working principle of the Ocean Cleanup system is as follows. Plastic is moved by currents whereas the system is propelled by currents, waves and wind, which yield higher relative speed than plastics. That allows the plastic to be accumulated within the system. When gathered debris reaches certain amount it is collected by "garbage truck of the seas" to process and recycle on land. The Ocean Cleanup estimated that a fleet of sixty systems is able to clean 50% of Great Pacific Gyre in five years. Furthermore, it is stated by the team that if a similar fleet is launched into other garbage patches, up to 90% of plastic in those patches would be removed by year 2040.

System 001 was launched for a two-week testing on 8th of September 2018. It was deployed 240 nautical miles offshore from San Francisco. In trials the team was testing assembly of the system and self-navigational ability as well as measuring its speed, optimizing its span and testing for structural robustness. All the tests had satisfying results so the system was sent to the Pacific garbage patch.

On the 18th of October the system was delivered to the Great Pacific garbage patch, where it was tested for two more weeks. After successful trial the system was deployed further in the patch and the first clean-up has officially started. During the following four weeks a problem was discovered - the system did not retain plastics for a long period of time. The reason for this is that in some cases the system was moving slower than the plastic, although it needs to be moving faster continuously. The system was modified to be 60-70 meters wider to increase surface area exposed to propelling winds and waves but the changes were not effective enough. On the 29th of December an 18-meter long part of the system detached, so it was decided to bring the system back to port for further analysis and modifications.

System 001 was at the location for approximately four months instead of intended six. During that time, it was successfully confirmed that system can retain its shape and self-orient in winds and waves. At the same time, it was learned that plastics moves faster than expected and system sometimes moves slower. The structural failure was found to be due to fatigue at one of the welds, so design of next system will be improved. At this time, the main issue is retention of plastics, so the team is looking into possible solutions. ("The Ocean Cleanup," 2019)

4.1.3 4Ocean

4Ocean is a company that started with two surfers terrified by the amount of plastics in the ocean at Bali, Indonesia. Andrew Cooper and Alex Schulze have decided to clean the ocean and the coastline with the help of local fisherman by paying them for each pound of plastic they recover. Every person in the world is able to contribute to their goal by purchasing the 4Ocean bracelet made from 100% recycled materials. At the moment, 4Ocean has pulled over four million pounds of trash with support of people purchasing their bracelets. ("4Ocean," 2019)

To meet their ambitious goal the team has designed an Ocean Plastic Recovery (OPR) project to stop plastic from entering the ocean at the river mouths. The purpose of the project is to barricade the river mouth and retrieve all the plastic while it is still easily accessible. In the scenario developed by the team, an ocean plastic recovery vessel (OPRV) comes to highly polluting river mouths and sets up a barricade that traps all the plastics. The barricade is designed in a similar way to the Ocean Cleanup system except it is stationary and is of a smaller scale. (“4Ocean,” 2019)

OPRV will be equipped with two cranes and four “panga” boats (local fisherman’s boats called like that). When the OPRV is at the river mouth and the barricade is set up, panga boats are lowered from the ship to the water so that locals can collect all the trash. When the maximum load of the boat is achieved it returns to OPRV where the crew cleans and sorts collected debris. Sorted trash is then moved to the recycling facility. If the project is successful, 4Ocean will be preventing large volumes of marine debris from spreading while providing jobs for local population and reducing need for virgin materials. Unfortunately, there is yet no information when the OPR project will be deployed.

4.1.4 The great bubble barrier

The Great Bubble Barrier is an air bubble obstacle installed in the rivers to prevent plastic from flowing into the ocean. Essentially it is a device located at the river floor that consist of pipe with holes through which air is pumped. The air flow traps plastic and brings it to the water surface. At the same time, it allows the fish and the ships to cross the barricade safely as there is no physical barrier in the river. If the device is located diagonally, the air flow and the current bring the plastic closer to the coast for easier accessibility and collection. Working principle of the barrier is shown in Figure 21.

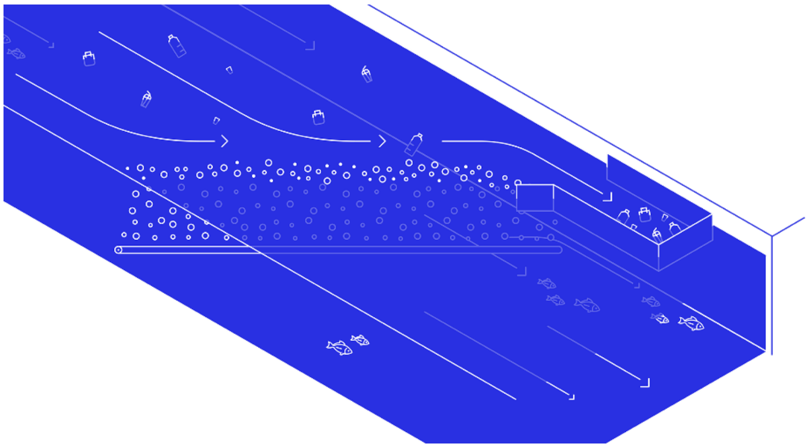

Figure 21. The Great Bubble Barrier's plastics collection principle ("The Great Bubble Barrier," 2019)

The Great Bubble Barrier is an air bubble obstacle installed in the rivers to prevent plastic from flowing into the ocean. Essentially it is a device located at the river floor that consist of pipe with holes through which air is pumped. The air flow traps plastic and brings it to the water surface. At the same time, it allows the fish and the ships to cross the barricade safely as there is no physical barrier in the river. If the device is located diagonally, the air flow and the current bring the plastic closer to the coast for easier accessibility and collection. ("The Great Bubble Barrier," 2019)

The technology has been tested in cooperation with several organizations and repeatedly showed successful results. It was proven by the team that the barrier function under variable environment conditions such as strong wind and currents while still capturing up to 86% of passing waste. Although the technology is very promising there are still no permanent installations in the rivers. The team aims to bring the technology to the most polluted rivers in Asia by year 2021.

4.1.5 Mr. trash wheel

Figure 22. Mr. Trash Wheel (“Mr. Trash Wheel,” 2019)

“Mr. Trash Wheel” is the stationary inner harbor litter interception technology. The purpose of the devise is to collect all the trash in the barricaded waterway. It is equipped with a skirt that allows to capture underwater debris as well. The water wheel is the engine of the device and it is powered by the current and solar energy when the current is not strong enough. The wheel rotates the conveyor to collect all the trash into a replaceable garbage pail.

The most the Water Wheel has ever collected in a single day is 17,250 kg. So far the wheel has collected over half million plastic bags, 11 million cigarette butts, over a million foam containers, 900 hundred thousand plastic bottles and almost four thousands sports balls. Trash collected by the Water Wheel is incinerated to generate electricity and some of the waste is sold as souvenirs. (“Mr. Trash Wheel,” 2019)

5 RESULTS AND DISCUSSION

5.1 Findings: sources of marine pollution

Modern day life is almost unimaginable without plastics products. Plastics have made our life easier and more convenient and have several important benefits over other materials, such as durability, low cost, low weight and chemical stability. For example, lightweight and flexible design of packaging allow to transport more goods per journey, resulting in lower fuel consumption and emissions. Plastics also prolong shelf life of many food products leading to much lower food waste rates. There are numerous other applications that make plastics highly desirable such as medical equipment, building insulation, windows, personal safety equipment and many other.

Clear advantages of plastics have created high demand over the past 70 years, leading to production rates of about 350 MT/y nowadays. The rise of production rates also is a result of rise of population and its average income levels, as well as economic incentives such as low manufacturing costs and rapid production. The problem, evident from Figure 16 is that policies, waste management and local sustainability measures were developing at a slower rate than the global plastics manufacturing. Mismanaged plastics waste takes indefinite amount of time to decompose, especially in the marine environment. It has started to rapidly accumulate, triggering concern for environment, wildlife and even human health.

When looking from geographical perspective, Asia is seen as the most polluting area, constituting over half of the global plastics production (Figure 23). As concluded from Table 1, counties that produce the most plastics do not necessarily contribute the most to pollution. Factors such as population size and effectiveness of waste management system also play an important role. The presentation of statistics also matters for country ranking. China ranks 1st in the Table 1 and Malaysia ranks 10. However, if mismanaged waste was calculated as a unit of waste per year per person, Malaysia would score 38 kg/person and China would be at 33 kg/person. Another way to divide is by category, where packaging and consumer products constitute 60% of plastics waste together (Figure 24).

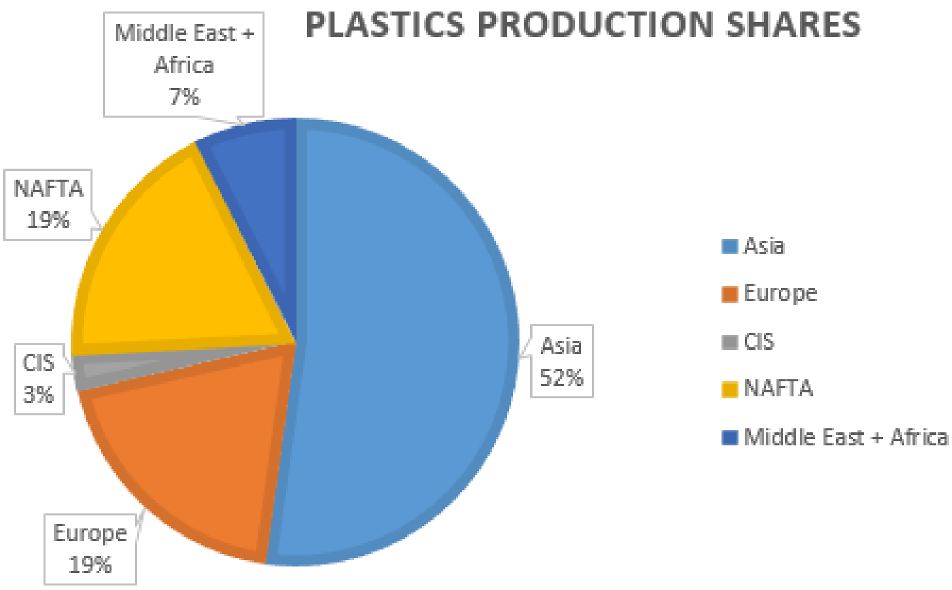

Figure 23. Plastic production shares worldwide by economic zones

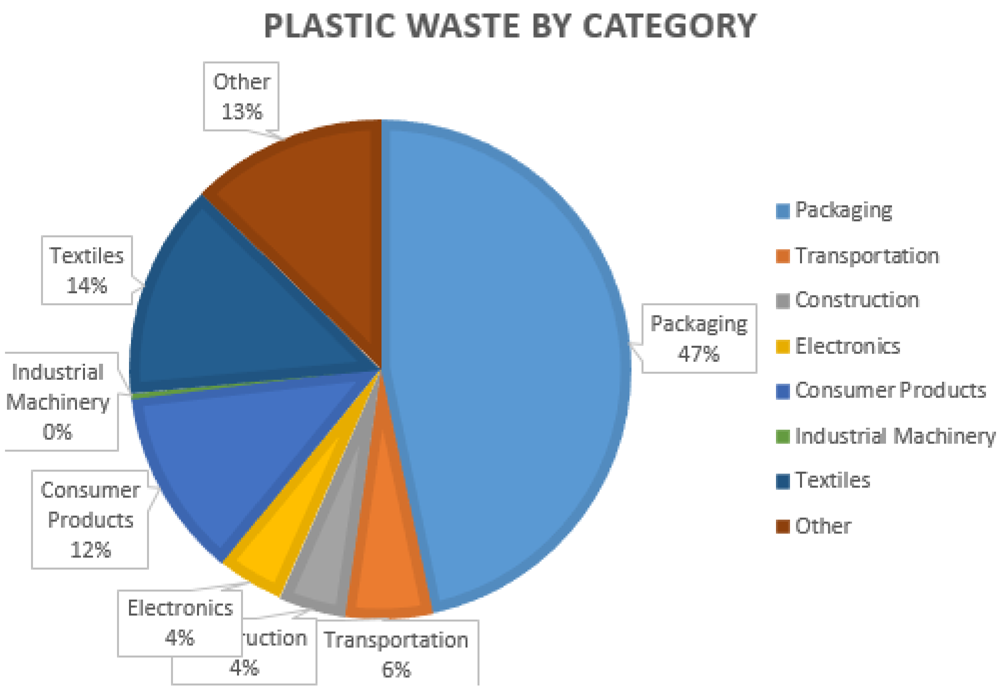

Figure 24. Shares of global plastic waste per category

There is a clear need to focus on problem of environmental pollution worldwide, especially in countries, where the potential for improvement is highest. As shown by Jambeck et al. (2015), waste management infrastructure needs to be developed further in Asian region in order to significantly cut down pollution. Similarly, global action should be taken with regards to single-use plastics, which constitutes the largest share of plastics waste. There is a need to develop reuse and return schemes, introduce alternative materials and alter consumer patterns for many objects in this category.

Another important finding of this study is that there is much more waste in the oceans than it seems at first. According to some estimates, around 1-5% of the ocean plastics is floating on the water surface or is easily visible. Large amounts of ocean plastics have washed up ashore, sunk down to the sediments or fragmented into smaller particles. Microplastics constitute a large share of plastics that is still a rather new research topic. The effects of microplastics on ocean's eco-system are not well understood yet, but there are concerns about ingestion by species, release of toxins and transfer of alien species between habitats.

Plastics reach the ocean through multiple pathways. The most common way is to look at pollution as land- and sea-based. It is believed that about 80% of pollution happens from land-based sources and remaining 20% from sea-based. It is important to note, however, that this is just a rule of thumb, which does not reflect reality in each and every area. In some cases, reverse situations have been observed, especially in places where fishing activities are high. Fishing gear has been identified as one of the immediate threats to wildlife due to frequent entanglement cases and high mortality rates. Further actions are needed for prevention of loss or discharge of fishing gear into the waters. Among proposed actions are increased levies for manufacturers of fishing gear and its marking so identify potential owners. The most common types of sea-based and land-based sources of pollution are summarized in Table 4 and Table 5.

There are also numerous pathways for plastics reaching the oceans. Natural forces include wind gusts, flooding and river streams. Other pathways include accidental spillage, drains and sewers, direct littering at sea or beach as well as improper disposal of plastic waste by industry and retailers. There is certainly a need for centralized method of assessment of sources and pathways of marine litter. Data about locations of entry points, demographics, types and sizes of pollutants need to be collected in synchronized manner around the globe to get a comprehensive view of the big picture. Additional activities are required to measure individual contributions of rivers, wastewater streams and other major pollution pathways. As mentioned previously, some presently used information, like ocean-based sources, is few decades old and require an update.

Table 4. Most common types of sea-based plastics litter by sector

Source of debris	A common type of debris
Fishing fleet	Fishing gear, packaging and storage boxes, personal items
Aquacultures	Buoys, structures, ropes, packaging and storage boxes, personal items
Merchant fleet & Offshore	Lost cargo, packaging, personal items
Sea and nearshore Tourism	Personal items, packaging

Table 5. Most common types of land-based plastics litter by sector

Source of debris	A common type of debris
Raw Material Producers	Pellets and granules
Manufacturers	Pellets, process waste, packaging materials
Retailers	Packaging, consumer goods
Transportation	Accidental spillage of any plastic goods, tires wearing
Littering	Personal items, packaging, cigarette butts
Improper disposal	Personal hygiene, consumer products, packaging, microbeads
Beach activities	Consumer products, packaging, cigarettes, bottles
Landfills	Any plastic goods blown off or carried by streams in flooding events

5.2 Findings: impact of plastics on marine wildlife

The accumulation of marine plastic waste is clearly a threat for marine environment. The degradation process is much slower in seas than on land, especially in remote areas where sun does not reach, little abrasive motion happens, and ambient temperatures are low. Plastics of all forms and sizes, from meso- to nanoplastics are present in sediments, water column, sea surface and on beaches. On top of that, larger plastic objects are continuously supplying environment with new micro- and nanoplastics through fragmentation process. It is estimated that at this rate, there will be more plastics than fish in the oceans by year 2050 (Joan et al., 2016).

Large amounts of particles are interfering with marine eco-systems, affecting even smallest inhabitants of the sea – those effects are summarized in Table 6. Summary of effects of plastics on marine wildlife. There are many species that mistake plastics for food or accidentally swallow it while hunting. By now, there are records of ingestion or entanglement by all known species of sea turtles and more than half of known species of sea mammals and birds.

For example, Gall and Thompson (2015) found at least 13,110 reports about ingestion of plastics by more than 200 species. The majority of ingestion incidents were associated with small plastic fragments. Size, shape and color of plastics can fool animals into thinking it is edible, leading to repetitive ingestion until food tract is full. Some species accumulate plastic debris in the gut. In such cases starvation might end with a death. Other species will regurgitate fragments, taking less impact from ingestion. Ingested plastics may release toxins that can result in poor feeding activity, lower reproduction rates and decrease overall survivability. In the long term, toxins released from the ingested plastics accumulate in the body tissues and travel up the food chain. Over 30,000 reports of entanglement were identified for 267 species. Most of the entanglement cases were due to plastic ropes and netting. Entanglement is seen as direct threat to marine life, as usually it would result in death of species.

Table 6. Summary of effects of plastics on marine wildlife

Category	Most popular plastic types	Impact
Entanglement	Fishing nets, straps, monofilament lines, nondescript lines, ropes, plastic bags,	Drowning, starvation, movement restriction, traumas, infections, exhaustion, vessel strikes
Ingestion	Any plastics that look like prey to wildlife. Especially microplastics of different colors, bags and lines.	Infection and blockage of digestion track, internal bleeding, reduced urge to feed, intoxication, cancer, endocrine disruption, immune impairment, neurological damage, reproductive failure, developmental delays
Transfer of alien species	Any floating plastics, such as low density, or with enclosed bubbles	Extinction of species, reduction of biodiversity, change in ecosystem

Other impacts of debris on marine life is release of harmful additives into the water, transfer of alien species across long distances and potential of significantly altering local eco-systems. There are multiple additives that can have negative significant effect on live organisms. More research is required for identifying particularly harmful additives to wildlife and restricting their use in production. Furthermore, research about ingestion of micro- and nanoparticles is still very recent. There is lack of knowledge about impacts of micro- and nanoplastics on marine organisms and whether they pose a threat to human health as well.

It is evident from literature, that marine litter is having an increasing effect on marine biodiversity. Further, it is seen that there is no universally agreed sampling and reporting method for measuring impacts of plastics on marine life. Ocean is a dynamic system, so location, sample size, time of a day and year all have influence on the collected statistics about ingestion and entanglement. There is very limited information about submerged plastics and their fate in the marine environment.

5.3 Findings: remediation of marine plastics waste

The problem of marine litter has gained significant attention over the past three decades. Presently, there are numerous awareness and education campaigns, legislation development, clean-up technologies and volunteering activities and even more initiatives are under way. Those activities are interconnected parts of the solution to marine pollution, but all have varying effect. The discussed strategies and approaches are summarized in Figure 25.

If plastic pollution could be compared with tap water overflowing, it would be more effective to limit flow with a valve at the source than to keep collecting overflown water and pouring it back into the full sink. Therefore, research and prevention go hand in hand towards eliminating marine pollution. Research is important for identifying and quantifying sources, pathways and impacts of pollution. With knowledge in hand, effective preventive measures can be taken by focusing on solutions with highest potential in pollution reduction.

Prevention at source has the highest potential because it impacts large volumes of produced waste and in some cases reduces the production volume as well. Legislation, public awareness, alternative materials, downgauging, the 4R (reduce, reuse, recycle & recover) strategy – those are the upstream measures that need to be implemented in the first place. As a result of upstream measures, pollution decreases together with demand for natural resources.

The next effective step is mitigation of waste before it becomes litter. At this stage we have tools to minimize waste leaks by establishing efficient waste management systems, introducing new recycling schemes and encouraging proper disposal of used products. The plastics saved from becoming litter reduce demand on pristine materials or can be used for energy recovery instead of burning fossil fuels. This approach is the idea of circular economy, where material's lifecycle is no longer considered linear but instead it has several lifecycles.

The final step is to address pollution at hot spots by recovering waste that has already accumulated in the ocean and by cleaning litter in the coastal areas and deeper in-land. Those methods vary in efficacy depending on scale and location of clean ups. Cost effective locations such as river mouths and beaches are good examples where marine pollution can be still addressed quite effectively. More remote areas with dispersed plastics, however, might be economically and environmentally inefficient. Projects like Ocean Cleanup might be a feasible solution to plastics that is free floating in the ocean, but it is yet to prove effective. In the near future, there might not emerge a solution for submerged plastics and microplastics, which constitute a large proportion of marine litter.

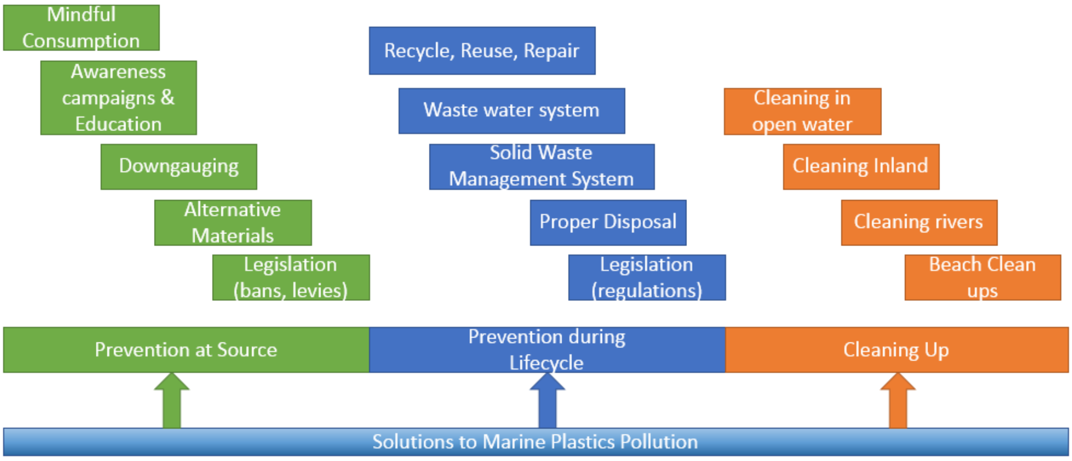

Figure 25. Summary of activities resulting in cleaner ocean

6 CONCLUSION

This work has become a rather broad overview of the topic of marine plastics pollution. It was found that plastics and microplastics are the most common ocean debris that is present even in the most remote areas of the world. The amount of debris is likely to continue increasing in the near future due to increasing production volumes and lagging development of infrastructures, policies and campaigns that cultivate sustainable society. The problem of marine pollution has significant impacts on social, economic and ecological spheres both short- and long-term. The following answers were found to the posed questions through literature review.

What are the main sources of plastics waste and its pathways to becoming marine plastic debris?

Human activity is the cause of the majority of environmental problems we are facing right now. Marine plastic debris is a perfect example of pollution caused exclusively by humans. The highest contribution to marine pollution comes from land-based sources, especially coastal cities with high population and poor waste management system. Big population creates big volume of generated waste, while poorly organized waste management system results in big share of trash losses to the environment. Big volume of generated waste together with large share of losses consequently result into large volumes of marine litter. The most common type of land-based plastics waste are single-use and consumer products. Other notable land-based sources are intentional littering, improper disposal and waste leaks at manufacturing, transportation and distribution stages. The most common pathways for plastics waste to becoming marine debris are winds, natural and human-built waterways, accidental spills and direct littering near water.

For sea-based sources, fishing activities are responsible for large share of marine debris. They are mostly responsible for ALDFG type of debris in addition to single-use plastics. Merchant and passenger fleet as well as aquacultures are also contributing to the problem of marine plastic pollution although to a lesser extent.

How does plastics debris affect Ocean's wildlife?

Even though land-based sources produce more marine litter, sea-based sources might have higher immediate consequences for the wild-life. ALDFG objects such as fishing nets, monofilament lines and packaging straps made from plastics take long time to degrade and can physically harm an enormous number of marine animals through entanglement.

Marine plastics of all sizes and shapes are accidentally or intentionally ingested by marine species of all sizes – from whales to microorganisms. Immediate effects of ingestion can be increased animal vulnerability and starvation. In addition, ingested plastics can release toxins in the body. In long-term, this could lead to shrinking of population sizes due to chronic diseases, decreased reproduction and lowered survivability.

The plastics might take hundreds of years to fully degrade in marine environment. Therefore, they are accumulating throughout the ocean, even in the most remote areas. The increasing amount of marine plastics poses a threat to delicately balanced local ecosystems through introduction of new species. This might cause further reduction of biodiversity that may cause a cascade of effects that we are not even aware of.

What are the existing preventive measures of plastics waste generation and how to mitigate already existing ocean contamination?

Methods of addressing marine pollution can be divided into two major groups. The first group is what we can do right now to immediately reduce flow of plastic waste into the oceans. Those include improving wastewater and solid waste management systems. The clean-up efforts, especially on land, beaches and at river mouths minimize the pollution that is already being caused. Technologies and activities organized by companies and organizations such as 4Ocean, Ocean Conservancy, Ocean Cleanup, SeaBin and many others are all important part of the action. In addition to removing pollutant from water they bring attention of media and society to the problem.

The long-term solutions are integral to altering the trends of the marine pollution. Those methods not only reduce the amount of generated waste but also decrease demand for resources. Among those methods are policies that eliminate fully or partially production unnecessary plastics items such as straws and plates, put tax and levies on the most littered items and introduce fines for littering. The most polluting categories are consumer and single use plastics. Therefore, measures for extending products lifecycle will greatly reduce production volumes. Such methods are downgauging, recycling schemes, moving from single-use to multi-use designs as well as introduction of alternative materials in place of plastics. Altering consumer behavior to a more sustainable oriented is a very important long-term solution as well.

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