Society Role in the Reduction of Plastic Pollution

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Abstract Globally, plastic pollution generates a dramatic environmental impact, posing an increasing hazard to wildlife and human health. Complex measures are needed at the societal level to curb this pollution trend: from changing consumer behavior, enhanced research for innovative solutions to reduce plastic production and increase plastic recycling ratio, to the usage of environmentally friendlier alternatives, improved awareness raising, and information dissemination at wider scales. There are multiple possibilities for public and stakeholders to break the plastic pollution chain: education, research, environmental NGOs, plastic industry, local authorities, policy makers, and citizens – all can play an active role in the battle against pollution. This chapter presents the ways to induce an attitude shift at the societal level toward reduction of plastic pollution, by emphasizing the risks of plastic pollution, possibilities to change consumer behavior, examples of best practices to reduce pollution and improve plastic waste management, highlighting how education and science can improve our daily decisions toward green solutions, how social media can support with dedicated applications and awareness-raising campaigns, and how each stakeholder can contribute to tackle this global challenge.

Keywords Awareness raising, Consumer behavior, Plastic recycling, Plastic waste management

1 The Global Dimension of Plastic Pollution

Plastic pollution generates an increasing concern at the global scale. While plastic products can improve the quality of human life, nearly half of the plastic production worldwide generates a substantial amount of waste, causing negative environmental impacts in case of inappropriate disposal. Following the increasing demographic trends and technical developments, plastic production has increased dramatically over the past decades, from a production of 1.7 million tons worldwide in 1950 to nearly 360 million tons in 2018 [1]. At the present rate, this value is estimated to double within the next 20 years, accounting for 20% of the global oil consumption and 15% of the annual carbon emissions by 2050 [2]. In a business-as-usual scenario, this projected increase in plastic production will most likely result in a concomitant increase in the accumulation of mismanaged plastic waste in the environment, which is projected to triple to 155–265 million ton $year^{-1}$ by the year 2060 [3].

Most plastic litter enters the environment through inappropriate disposal and/or management of plastic products. It is considered that about 80% of plastic pollution in the marine environment originates from land-based sources [4]: only in 2010, between 4.8 and 12.7 million metric tons of mismanaged plastic waste entered the oceans globally [5], either through direct input into the sea or via rivers, activities on the shoreline, shipping, and fisheries.

At the global level, the Asian continent contributes in the highest extent to plastic waste generation and pollution. For example, in 2015 the top five regions generating plastic waste were Asia (82 million ton), followed by Europe (31 million ton), Northern America (29 million ton), Latin America (19 million ton), and Africa (19 million ton); however, the proportion of inappropriate plastic waste disposal, responsible for plastic pollution, showed a different ranking: Asia released an average of 52 million ton of plastic waste into the environment, followed by Africa (17 million ton), Latin America (7.9 million ton), Europe (3.3 million ton), and North America (0.3 million ton) [3]. The authors conclude that the unfair practice of importing waste, especially e-waste, from developed nations, is to a large part responsible for this problem, e.g., in Africa ([6], cited in [3]). These data show that the plastic pollution problem is more acute in developing countries; moreover, moving plastic waste from developed countries to developing areas only increases the problem, without offering real solutions to reducing plastic pollution. Hence, additional efforts to improve plastic management should be made by all countries, especially by those producing high amounts of plastic.

Once entered in seas and oceans, floating plastics are driven by currents, accumulating in large patches and gyres, the largest one being the Great Pacific Garbage Patch, located in the North Central Pacific Ocean, between Hawaii and California. The aerial estimates of this area covered by plastic waste trapped by winds and currents indicated in 2018 a surface of over three times the size of continental France rapidly growing due to increasing amounts of plastic waste brought in the area [7]. However, this is only the tip of the iceberg, with floating plastic debris representing only 5% of the total, while the rest of 95% are submerged [8], making it impossible to clean all plastic waste from the marine environment.

While most plastic debris are generated by an inappropriate collection/recycling of plastic products, microplastics originate either from the fragmentation of macroplastic products, like packaging, textiles, dyes, car tires, etc. (secondary microplastics), from industrial products containing added microplastic particles such as cosmetics and healthcare products (cleansers, exfoliators, toothpastes, sunscreen creams), or from synthetic fiber clothes [9]. These so-called primary microplastics also include, e.g., industrial raw pellets, ion exchange resins, sand blasting media, etc. Microplastics can be transported by wind, washed into aquatic environments by runoff, or released from wastewater treatment plants, where they are incompletely retained during purification processes and then discharged into rivers and waterways [10].

2 Why Do We Need to Reduce Plastic Pollution?

Besides the aesthetically detrimental aspects generated by the ubiquitous presence of the plastic debris in the environment, even on remote beaches (Fig. 1), it is becoming increasingly clear that plastic pollution can have negative impacts on the aquatic environment, with one of the most obvious effects being the increased incidence of ingestion and entanglement of marine birds, amphibians, and mammals due to plastic litter [11, 12].

There are still significant knowledge gaps regarding plastic presence and impact in freshwater bodies, especially in rivers that act as transport vectors (Fig. 2), connecting the land-based pollution sources to the seas/oceans [13]. Preliminary investigations of several European rivers (Rhine, Main, Danube) have emphasized the presence of plastic pollutants [14], but the extent of this contamination and its impact on water quality and aquatic biota, including on game and fish used for human consumption, are unknown. An alarm signal was already raised by researchers, as synthetic polymers such as polyethylene, polypropylene, and polystyrene are frequently found in rivers [15], while the contribution of other compounds still needs to be assessed. It has been shown, however, that a variety of different polymers is introduced into aquatic environments by wastewater treatment plant effluents [16]. Considering that river water has multiple uses for human society (drinking water, water for irrigation and livestock, fishery and aquaculture, food industry, etc.), the likelihood for the ingestion and transfer of the plastic present in the rivers into the food chain increases with the pollution.

Fig. 1 Plastic waste along remote beaches (Marinella di Sarzana, Italy). Photo credit: Franco Borgogno

Fig. 2 Plastic waste accumulation along inland rivers (Po River, Italy). Photo credit: Franco Borgogno, LIFE VISPO project

Regardless of their entry source, once arrived in the aquatic environment, plastic particles can impact not only large vertebrates but also other living organisms, posing possible hazard also on human health [17, 18].

The risks to wildlife generally fall into three main categories:

(a) Physical harm (e.g., entanglement, irritation/blockage/perforation of the digestive system, false satiety, suffocation/damage to benthic systems)
(b) Chemical harm (from toxic chemicals associated with plastic such as additives, persistent organic pollutants, heavy metals, etc.)
(c) Biological harm (e.g., from microorganisms that adhere to plastics)

Entanglement and ingestion of macrodebris by large vertebrates is undoubtedly a significant issue (Figs. 3 and 4); however, microplastics can also be ingested by aquatic organisms and transferred along the food webs [19].

Moreover, unaware of the danger, birds use plastic debris to build up their nests [20], exposing their offsprings to possible accidents in early life stages (entanglement, ingestion of plastic particles with the food) (Fig. 5).

In general, negative consequences of plastic on aquatic fauna include loss of nutritional value of diet, false satiety, impaired reproduction, physical damages, exposure to pathogens, and transport of alien species [21, 22]. In addition, plastics contain chemical additives able to leach into the environment and the food and

Fig. 3 Two male specimens of common eider (*Somateria mollissima*) entangled in an abandoned fishing net while diving to hunt small fish in the Gulf of La Spezia, Italy (Photo credit: Davide Lopresti)

Fig. 4 Young subantarctic fur seal (*Arctocephalus tropicalis*) entangled in plastic strings and ropes (Photo credit: Peter G. Ryan)

drinks we consume and efficiently adsorb other toxic environmental contaminants (e.g., endocrine disruptors), thus constituting a potential source of exposure to such compounds after ingestion [22]. The capacity of plastic particles to act as transport

Fig. 5 The Northern Gannets nest of Portovenere (Italy), built over the deck of a boat using large amounts of plastic materials. Reproduced from [20] with permission of the authors

vectors for other toxic pollutants, as well as their bioavailability through the trophic networks, increases the risks for wildlife and human health, but the ecological significance of this issue is still under discussion among scientists [23].

The ingestion of microplastic particles has been demonstrated in a wide range of marine organisms consumed as food by humans, such as molluscs [24, 25], crustaceans [26], and several fish species of commercial interest [27–33]. In addition to wild organisms, also those from aquaculture have been observed to ingest microplastics [34–36]. The presence of microplastics has also been detected in seafood sold for human consumption purchased from markets around the world [37–39]. It should be noted, however, that human ingestion of large microplastics via seafood is probably more common for shellfish and small fish which are eaten entirely including the gastrointestinal tract and probably less frequent for large fish which are generally eviscerated before consumption, thus minimizing direct exposure to microplastics.

All this evidence raises concerns regarding the consumption of microplastics by humans, though, at the current levels of contamination, the hazard on human health needs further evaluation. More recently, the potential risk of nanoplastics (<1 μm in one dimension) in seafood is being recognized [40], even though research is still in its infancy. Compared to microplastics, nanoplastics have an increased mobility in the tissues of living organisms [41], and their larger surface to volume ratio increases their potential to adsorb and concentrate toxic chemicals and heavy metals [42]. Translocation of plastic particles across the gastrointestinal tract has been demonstrated in the laboratory for crabs [43] and mussels [44] and in the liver of fish fed with plastic particles [45]. Within this context, being more prone to translocation across biological tissues, nanoplastics would pose a greater potential

risk to human health [46]. However, impacts and environmental concentrations of nanoplastics are still largely understudied, and the risk posed to marine organisms as well as to humans who consume seafood requires further detailed research.

Plastic also has a significant contribution to climate change impacts. Plastic manufacturing is estimated to use 4–8% of yearly global oil production, and it was estimated that around 5 ounces of carbon dioxide are emitted for each ounce of PET produced [47]. Processing plastic resins and global transportation also have a carbon footprint, with estimates showing that one 0.5 l PET bottle has a total carbon footprint equal to 82.8 g of CO_2 [48]. In addition, also the accumulation of plastic litter in the environment is raising concern for potentially contributing to carbon emissions, with recent research showing that polyethylene and other commonly used polymers can release substantial amounts of dissolved organic carbon into the ambient seawater [49] and greenhouse gases (methane and ethylene) into the atmosphere, when exposed to solar radiation [50].

As the plastic pollution was generated by human society and now turns back like a boomerang, affecting environment and human health, it is our responsibility to take action and reverse the current pollution trends. Science, education, stakeholders involved in the plastic cycle, NGOs and the general public all have a major role to play in the next years, each one contributing with essential pieces to solve the complex puzzle of plastic pollution.

3 Role of Research and Education

In the last decade, the focus on emerging water contaminants was mostly placed on pharmaceuticals, persistent organic pollutants, and nanomaterials. In recent years, however, a new suite of contaminants, predominantly microplastics, received increasing attention after being frequently detected in marine, and more recently in continental waters and sediments, and after the alarm signals pulled by scientists regarding the potential risks they pose to biota. In this context, macroplastic contamination is also of very high concern.

3.1 Research

Although research concerning the impact of plastic on the aquatic biota is in its early beginning, the studies performed so far already emphasize that plastic particles can negatively impact aquatic wildlife and human health [51].

Preliminary investigations have indicated the capacity of microplastics, and the pollutants associated with their presence, to bypass wastewater treatment plants and enter the trophic food chains at low trophic levels, from where, through bioaccumulation and biomagnification, they can also reach end consumers [52].

Considering the widespread use of freshwater for drinking or agriculture and the fact that many aquatic species are used as food source (fish, crayfish, mussels, etc.), it is easy to understand that contaminated drinks and food also reach humans.

Research was paramount to reveal the contamination levels of microplastics and microfibers in many food and drink products intended for human consumption such as honey [53], salt [54], beer [55], and drinking and tap water (see [56] for a review), triggering in this way surprising reactions from the public opinion and the decision-makers as well.

However, there are still many challenges ahead, such as highlighting the level of plastic contamination in general, emphasizing polymers occurring with higher frequency and higher concentrations in the natural environment [57], assessing plastic uptake, accumulation, and transfer rates to different aquatic organisms and human bodies, and evaluating their ecotoxicological impact [18, 58] and effects on health (life cycle parameters, metabolism, stress) – in conclusion, enabling a reliable risk assessment, tracking the pollution sources, and recommending ways to phase them out. Interdisciplinary studies combining chemistry, biology, toxicology, ecotoxicology, and health sciences should be directed toward the identification of high-risk plastic substances and for substituting their use with environmentally friendlier products (paper, wood, bioplastics, etc.).

Research should also be directed on studying the plastic impact on aquatic habitats and innovative ways to restore polluted sites. Collecting plastic from aquatic habitats is a big challenge especially in dynamic rivers, which are constantly changing their characteristics. While for macroplastic the collection is easier (floating in pools near the river banks, in the vicinity of obstacles such as trees or dams, or from the river banks and adjacent floodplains) and plastic items can be recycled, microplastic particles already released into the environment are too small to be eliminated without affecting habitats and biota. Creating buffer strips along the rivers (wetlands, floodplain forest) to retain plastic products and facilitate their collection, improving the efficiency of microplastic retention in wastewater treatment facilities by including additional filtration steps, designing innovative solutions to prevent plastic to reach the rivers should be explored as possible solutions to reduce the plastic input into the aquatic environment.

Replacing the most common single-use synthetic polymers, for instance, with biodegradable polymers, is often considered as one of the most effective solutions to solve the plastic pollution crisis [59]. Research into the degradation times and environmental effects of these new polymers, however, is still in its infancy – especially in the marine environment where many biodegradable and oxo-degradable materials showed much lower degradation rates than in laboratory conditions [60] – and instruments such as the Life Cycle Assessment (LCA) should be always used to clearly point out the benefits or the disadvantages of using these new polymers before adopting binding legislative decisions (e.g., [61, 62]).

3.2 Education

Education has a key role in shaping a responsible behavior of the future adults. Considering that reducing plastic pollution is a long-term endeavor, it is essential that children and young people receive sound knowledge concerning the effects of plastic pollution and ways to reduce its impact by our daily behavior, as they represent the future generations.

Educational programs prepared for pupils may include classrooms and outdoors experiences to learn about how much plastic they daily use, plastic impact on the environment, particularly on rivers and seas, how human life is connected to the freshwater ecosystems, how aquatic pollution may affect them, the importance of reducing the use of plastic, reusing it, and recycling it, and, finally, how important it is to avoid littering in general. Beyond the environmental problem of plastic waste and with respect to limited fossil resources, such programs should also distribute the knowledge that plastic waste has a high energetic value and can be used for energy recovery – thus plastic littering is not only of environmental concern but also represents a waste of energy.

The involvement of pupils in such activities can be further pursued by field trainings to observe plastic pollution and communicate their results, school contests and participation in river, lake, and beach cleaning actions (Figs. 6 and 7), and

Fig. 6 Children cleaning up the bank of the Meuse River, Netherlands. Photo credit: Gijsbert Tweehuysen

Fig. 7 Teenagers collecting plastic waste (Po River, Italy). Photo credit: Franco Borgogno, LIFE VISPO project

activities that are meant to stimulate their willingness to act as volunteers, advocating and disseminating within their families and groups the information acquired about the need to reduce plastic pollution.

One of the education programs in Italy and Hungary promoted by the European Research Institute (ERI) based on the UNESCO guidelines [63] and toolkit [64] is about Ocean Literacy. The program takes into account the fact that most people are unaware of the impact of their daily actions on the health and sustainability of the oceans and the resources they provide. This program strengthens the understanding of the importance of ocean health for human lives at the social, economic, and political level since early ages. Special focus is placed on students, where using short presentations and combining education with cleaning plastic waste activities target an attitude change by cognitive, socio-emotional, and behavioral learning. A successful cooperation was also established with schools, targeting the organization of joint education events such as collection of plastic waste along the river shores and sea.

The education ideas formulated by ERI are based on the so-called de-linearizing learning approach [65], supporting people to overcome challenges and identifying four important roles in learning: student, teacher, researcher, and practitioner, all of which should be used by each individual in the education process. The education process follows a three steps sequence:

- *The process of acquiring, making accessible, and where necessary, developing new knowledge and skills*, where finding appropriate knowledge is essential to define the requirements for a collaboration system facilitating the learning process.
- *Assessment and quality assurance*: Given the fact that every person involved in the learning process can play the role of a supplier of knowledge (teacher or researcher role), the quality of the information itself should be assessed.
- *Integrating into the worldview* – the actual teaching process, where a growing number of specialists will be involved in the teaching process, resulting in the challenge of integrating the insights of the specialist into the existing world-views and/or systems of values and norms. Thinking concerning the roles an individual play makes it possible to introduce different levels of involvement at the individual, organizational, or societal level.

This type of education has an important role in the innovation capacity of people and offers practical experiences, thus being a very useful and successful methodology.

To ensure that the latest research findings on the issue of microplastics in marine ecosystems are directly incorporated into school lessons, marine researchers and museum educators have jointly developed teaching materials for four school levels as part of the PlasticSchool project in Germany, which are available online [66]. Similarly, the Citizen Science campaign "Plastik Piraten" offers school classes and youth groups the opportunity to actively support research into the nationwide contamination of plastics. Here, data collected by the students themselves can be made available to researchers for data evaluation. Furthermore, information, teaching, and working materials are made available free of charge on the project website [67].

Considering that plastic pollution is an emerging issue, there is a high need to build capacity of the future scientific and national authority staff in this area and address dedicated programs in student education and training, including bachelor, master, or PhD programs. After graduation, they will be familiar with the state-of-the-art techniques for sampling, extraction, purification, and analysis of plastic samples from water, sediment, and biota and, hence, become multipliers at the national and international level. Communication and knowledge exchange with nonacademic organizations, as well as with stakeholders involved in the plastic cycle, will facilitate contacts with potential future employers (e.g., industry, environmental agencies) while enabling them also to look for sustainable solutions.

An important program was launched by UN Environment, in cooperation with Open University of the Netherlands, the "massive open online course" (MOOC) on Marine Litter [68] aiming to teach students through action-oriented learning on how they can apply successful and inspiring activities to their own local context, regardless of their profession or location. The course introduces different options and tools to combat marine pollution; it provides examples and case studies to inspire leadership at all levels, thereby increasing awareness of and stimulating

creative solutions to marine litter problems. Moreover, the course supports policy makers, practitioners, and managers who wish to connect with other professionals in order to enhance their knowledge on marine litter issues.

A key fact regarding education nowadays is the possibility to use modern alternative digital tools to take over the role that traditional education can play. Social media are intensively used by the youth and reach better results in terms of accessing and acquiring knowledge than schools. Education materials on plastic impact, collection, recycling, and reuse should be prepared based on state-of-the-art research results and best available technologies in order to provide suitable tools to generate a behavioral change of the next generations.

Besides educating school children and younger generations, improving solid waste collection and management would also require targeting adult consumers' behavior, with this being especially true for developing countries and transition economies. The experience proves that this is an achievable goal, with formal and informal education activities generally increasing the public's understanding of the problem, fostering and inspiring better social and environmental solutions through positive examples and misconduct stigmatization.

3.3 Innovation

Innovation has a key role in paving the way for identifying solutions to the current challenges posed by plastic pollution, from observation, monitoring, and assessment of the contamination level to phasing out toxic components and designing environmentally friendlier materials to replace them.

A special focus is placed on designing remote macroplastic observation systems for seas and rivers. Macroplastic observation systems along the rivers could provide useful methods, for example, for the estimation of fluxes, retention, and inputs of litter into the seas, which is a mandatory step before planning adequate pollution reduction measures [69].

While preliminary steps have been made to monitor the flow of floating macroplastics using automated camera systems (Litter Cam) developed during RIMMEL project [70] or a device developed for seas during SPlasH! project [71], using remote sensors for rivers is more complicated due to the sediment transport and turbidity, which can induce high interferences in the accuracy. Hence, a series of parallel testing of analytical methods with sensor measurements should be performed to calibrate the sensors and eliminate the discrepancies.

In the SPlasH! project, the presence, origin, and dynamics of microplastics in several ports (Genoa, Olbia, Toulon) are analyzed. The study focuses not only on plastics floating on the sea surface but also on fibers present in the water column and on the seabed, providing data on aspects such as understanding the dynamic of microplastics and studying the influx and quantitative incidence of various sources of microplastics from land to sea, as well as their distribution at various depths in densely populated and active areas. The biological impact of microplastics is

analyzed by studying mullets, the most common fish populations in the ports. Further, the results will be combined with climatological trends to predict the trajectory of plastic debris dispersed at sea. The information will be disseminated to the general public by using multimedia tools and public initiatives and by directly involving economic actors and citizens.

The LIFE Preparatory Project in Support of the European Solidarity Corps (VISPO) [72] samples and analyzes the microplastic in the rivers Po in Italy and Danube in Hungary with the support of volunteers. Cleaning up the rivers from canoes and kayaks provides a unique experience of volunteering and training for young people under 30, through a first-hand contact with the nature and the issues linked with it.

In the project "Schone Rivieren" in the Netherlands, citizen scientists are studying the amount and quality of litter deposited on the riverbanks of Dutch rivers. In 2018, on 200 locations, almost 77,000 pieces of litter were found, of which 84% were plastic [73].

Innovation is also important to design environmentally friendlier substitutes of toxic plastic compounds and new decontamination methods of the sites impacted by plastic pollution. Also, a topic of increasing interest in recent years is developing innovative technologies aiming to valorize the plastic waste and create new materials. For instance, many applications target the use of plastic waste for building pavements or roads [74–76], for civil constructions and decorative products [77, 78], and for thermal insulation systems, solar modules, etc.

The management of plastic waste can also benefit from innovative concepts, such as from the "tokenized community," aiming to support management by blockchain technology, to create an economic environment that facilitates stable and transparent waste management and revalidation conditions, as well as functionality of the recycling value chains, thus ensuring sustainability in the long term.

Mostly the sustainability of revalidation chains (from waste to reused products) suffers from economic fluctuations, which make it difficult to have entrepreneurs taking an active role in recycling activities for low value mixed and contaminated waste fractions. Still most technologies are available to revalidate both high-quality (like PET bottles) and low-quality plastic waste fractions (like mixed food packaging films), but the economic viability is not there. Subsidies are needed to fill this so-called chain deficit and can be supported by governments or by private parties, e.g., in Extended Producer Responsibility schemes. In the present economic conditions, it is very difficult to predict where and when a chain of revalidation activities is profitable or not. Subsidies can support the decision to invest in the necessary technologies.

Traditional financing systems are mostly based on some sort of push financing, by paying an operator a certain amount of money to recycle or transport a specific amount of material. However, this requires an advanced control system to check whether the agreed operations have been really fulfilled. Moreover, they may not be available in every country.

A more promising concept is based on pull financing, where real activities are rewarded by tokens, which operate as a new currency within the revalidation chain and which are validated by both governments and funds from the EPR scheme of plastic suppliers, based on ecological results that have been achieved. This guarantees entrepreneurs that it is profitable to collect and revalidate even low-quality materials because their activities are rewarded in tokens, which later get a value from the government and EPR funds. The value of the tokens can be established at such a level that the required societal goals are effectively met.

4 Role of the Plastic Industry

The vast majority of plastic materials are produced by polymerization of hydrocarbon monomers. Plastics are used for highly diverse applications from, e.g., simple packaging to medical devices. To adapt plastic physical/chemical properties to the specific application, different additives are included during the manufacturing process.

Once produced, plastic materials enter into a cycle involving processors, distributors, collectors, recyclers, and convertors. For a sustainable cycle, all partners should consider options reducing the impact on the environment, minimizing the amount of generated waste and reducing energy consumption. However, this cycle closes only in seldom cases, as very often not all the plastic produced is recycled and reused, generating thus high amounts of waste.

Only in recent years, a special attention was given to plastic conversion (reuse) into new products such as clothing, bottles, carpets, etc. in order to prevent waste generation. Very promising are also the technologies to depolymerize plastics to monomers (chemical recycling) in combination with subsidies [79]. Exploring bottom-up initiatives to decrease pollution and a close cooperation of relevant stakeholders with the authorities may result in valuable recommendations addressed to industry and/or wastewater treatment operators to reduce the inflow of plastic substances in the aquatic environment.

Although the type of plastic material should be indicated by manufacturers, this is not always the case, and it can be misleading. Some synthetic polymers react to heat, and, hence, it is not recommended to heat food in plastic because harmful substances could be more easily released. Moreover, it is important to note that plastic does not seem to decompose in nature, just splits into small pieces, interfering with the biogeochemical cycles of the elements [49].

Selective collection and recycling of plastics is important, but cannot solve the problem of plastics alone. At present, only 9% of all plastics in the world have been recycled [80], while plastic production is rapidly increasing. Hence, it is recommendable to reduce the production and use of plastics by eco-design, consumption, and especially by reduction of single-use plastic products.

There are multiple ways the plastic industry can contribute to reduce pollution, such as:

- Designing new biodegradable plastic materials with lower impact on the environment
- Reducing the ratio and amount of plastic materials in new products
- Manufacturing products with a longer lifecycle
- Using recycled plastic and displaying the ratio recycled/new plastic on the product
- Developing incentives to stimulate collection and recycling of plastic products (EPR schemes)
- Implementing best practices for recycling – reuse of plastic products
- Improving plastic waste management and cooperating closely with other stakeholders to close the plastic loop
- Reducing the use of microbeads in cleansing products or abrasive substances
- Supporting plastic removal from the environment (polluter pays principle)
- Developing and implementing chemical recycling facilities for mixed and polluted plastic waste fractions
- Organizing knowledge sharing events to support exchange on best practices and know-how transfer, etc.

Considering the strong connection between the land-based pollution sources and the aquatic contamination, a close cooperation of the plastic industry with water and waste management authorities is needed to discuss challenges and adapt the plastic production and waste management plans accordingly.

One example of fruitful collaboration involving local stakeholders recently led to the testing phase of biodegradable polymers for the offshore mussel farming. In this case, lost mussel nets were identified as widespread in the marine environment, especially in the proximity of aquaculture facilities [81]. This led some companies specialized in the production of plastic gear for fishing and aquaculture to start developing mussel nets made of biodegradable polymers prepared from starch and bio-based polyesters. These innovative products are now being tested in collaboration with local fishermen and aquaculture plants within the framework of international European research projects such as Plastic Busters, ML-Repair, DeFishGear, and EU GHOST.

Another example is Fishing for Litter (FfL), an initiative that aims to reduce marine litter by involving the key stakeholders such as the fishing industry and mussel culture farmers. The initiative, now widespread in several European countries, foresees and facilitates the direct removal of litter from the sea, including abandoned or lost fishing gear and mussel socks, while raising at the same time awareness of the significance of the problem amongst the fishing community. It was originally started by the North Sea Directorate of the Dutch Government in cooperation with the Dutch Fisheries Association in March 2000. Pilot schemes were operated by KIMO International in the UK, Sweden, the Netherlands, and Denmark until 2005. Then the program was established in numerous other countries leading to the removal of substantial quantities of marine litter from the seabed [82].

5 Role of NGOs and the General Public

The general public has a leading role in the process of curbing plastic pollution: our options can make a difference, from the moment we decide to purchase a certain plastic product until the moment we dispose it and it is further taken up for recycling or conversion into a new product or at least for energy recovery by incineration. If we do care about the environment, we can select less harmful alternatives – all we need is the right information and education.

NGOs can contribute to this process by connecting different categories of stakeholders to provide adequate information, by initiating actions and mobilizing volunteers, by launching supportive projects, dissemination events, and awareness-raising activities, and by showcasing success stories and best practices to provide models to other communities – in other words, they can be the engine triggering a society response to decrease plastic pollution.

One of the most known examples is 5 Gyres [83], an American NGO working on plastic pollution research, who started to raise awareness about plastic distribution worldwide [84]. Every year, they organize dissemination activities and at least one citizen science expedition around the world, creating a global network of "ambassadors" raising awareness on plastic pollution.

The Ocean Cleanup developed advanced technologies to clean plastics from the oceans [85]. Their research on the Great Pacific Garbage Patch (GPGP) show that around 80 million kg of floating plastic debris have accumulated there, with microplastics representing the majority of the estimated 1.8 trillion pieces of plastic. It is estimated that the systems developed by this organization could clean up 50% of the plastic waste trapped in the GPGP every 5 years.

Clear Blue Sea uses an unmanned robot (FRED – floating robot for eliminating debris) powered by sun and wind to clean plastic waste from the marine environment and rescue animals trapped in debris [86].

Waste Free Oceans (WFO) works to reduce the global impact of marine litter [87]. By mobilizing fisheries, recyclers, manufacturers, and policy makers, WFO aims to reduce, recycle, and ultimately reuse marine litter, mitigating the impact on both the environment and natural resources. It works with companies, big and small, who want to send a clear message of intelligent use of resources and protect our ocean environments. WFO partnered with the green cleaning brand Ecover and manufacturer Logoplaste to combine plastic trawled from the sea with plastic made from sugarcane and recycled plastic, in what was hailed as a world-first for packaging. Ecover used the launch of its Ocean Bottle washing-up liquid to highlight the long-term dangers of dumping plastic in the sea (Fig. 8).

WFO is currently expanding into a new area. The organization collects plastic from the ocean and rivers, mixes it with plastic collected from land, processes it into a plastic plant, and converts it into panels. These panels are used to build affordable houses/shelters for the local communities who have lost their homes in natural disasters, therefore contributing to the welfare of the population in the less fortunate areas [87].

Fig. 8 Ecover bottle developed by WFO from recycled plastic. Photo credit: Letitia Florea

In 2018, the organization launched a cleanup project in Bulgaria, having collected about 20 tones of PET from the riverbeds during various actions [87]. The project continued also in 2019, in close cooperation with major international partners, local authorities, companies, NGOs, and other stakeholders, aiming to increase the number of cleanups organized in the Danube basin. In relation with national and international recycling companies and leading European plastics converters, WFO will use as much as possible of the collected plastic debris, turning it back into new products. The goal is not only to contribute to being part of an end of pipe cleanup but to be actively involved in prevention while inspiring local and regional entrepreneurs to engage and further invest in recycling technologies, in line with the EU Circular Economy.

Another project aims to contribute to the prevention and the cleanup of plastics pollution in the Atlantic Ocean, by removing floating marine litter in São Miguel island and raising awareness of stakeholders, both policy makers and the public at large, by collecting information that documents the impact of marine debris, building the capacity of the project partners and supporting the mobilization of resources for a larger follow-up project that could cover the whole Azores area [87].

Waste Free Waters (WFW) is a Dutch NGO which launched a project in 2012 to clean the Meuse River from plastic waste in cooperation with regional and local authorities, water authorities, landowners, associations, environmental NGOs, and the general public. In a coordinated activity, the banks along the full stretch of the Meuse were cleaned yearly between March and May, with the involvement of all municipalities along the Meuse, communicating and facilitating most of the activities in their territories. This activity has spread

further to other rivers in the Netherlands, with hundreds of people being gradually involved. Consequently, the project was expanded and named "Clean Rivers," with numerous citizens being trained to monitor the presence of litter on the riverbanks [73].

Other NGOs such as Greenpeace [88], Friends of the Earth [89], Oceana [90], and Ocean Care [91] and networks such as Plastic Pollution Coalition [92] have launched public campaigns and petitions to reduce plastic pollution and are highly engaged in advocacy work to improve plastic waste management.

Citizen science plays an increasing role in raising public awareness on plastic pollution, as shown within SEACleaner project, a project involving students, NGOs, and Marine Protected Areas in Italy, devoted to monitor beach macro- and microplastic litter [93]. The evaluations have shown that students changed quantitatively their perception of beach litter causes and derived problems, and they improved their knowledge about the main marine litter sources and the role of the sea in waste transport and deposition along the coast [94].

Developing specific citizen science programs can foster their involvement in monitoring plastic pollution or for collecting samples to be further analyzed in specialized chemical labs. Moreover, following the example of the applications developed for the marine environment (e.g., EEA, Litterati, TrashOut), dedicated "apps" for the rivers should be created to acquire information about plastic pollution along the banks and water courses. By training citizens on using these apps to monitor and report plastic pollution to water management authorities, the information could be used to design proper intervention measures for cleaning water and river banks in critical sections.

Creating educational programs and field events for pupils and teens to raise their support for pollution reduction measures and nature conservation activities is another important measure to be taken, provided that young persons are more receptive to environmental problems. This can contribute to induce a behavioral change for the young generations, as they will be aware of the risks posed by plastic pollution to human and wildlife health and can positively influence their networks.

The societal research and interviews made obvious that there is a lack of scientific knowledge among the citizens, and people are not aware about their roles as stakeholders involved in the plastic cycle. Based on these facts, a practical education model was developed using leisure and nature-related activities and selecting well-known and respected people to play role models to the different generations [95].

A very good inspiration can also be provided by local youth initiatives, such as #FridaysForFuture, which started in August 2018 when a Swedish 15-year-old girl Greta Thunberg protested for 3 weeks against the lack of action on the climate crisis. She posted images of her strike on Instagram and Twitter, and it soon went viral. The hashtags #FridaysForFuture and #Climatestrike spread, and many students and adults began to protest outside of their parliaments and local city halls all over the world, inspiring youth from over 140 countries and addressing world leaders at the UN conference on September 23, 2019 [96].

Education and awareness in our lives is crucial. If more people will start selecting carefully plastic products they use or the way they dispose it, the public behavior will gradually change, triggering a significant reduction of plastic pollution.

6 Communication and Awareness Raising

One of the most effective long-term measures to reduce plastic pollution is to significantly raise awareness of the society on the benefits of reducing plastic pollution for the environment and human health and trigger a shift of the current consumer behavior. By mobilizing support of major stakeholders, innovative solutions could be identified to improve collection/recycling systems, incentivize plastic reuse, reduce contamination at the source, secure circular management of plastics, change plastic composition, and replace harmful substances with environmentally friendlier compounds, etc.

Key messages should be addressed to different target groups, including high-level policy makers, waste management authorities, environmental protection agencies, plastic and cosmetic industry, wastewater treatment plant operators, economic partners, local authorities, research organizations, education units, NGOs, etc. Social media campaigns explaining the risks of plastic pollution, emphasizing impact on wildlife and human health, and informing citizens on simple ways to reduce it should be launched in parallel to increase the public outreach.

Awareness-raising activities need to involve the scientific community, considering that this can provide sound state-of-the-art information on the most frequent occurrence of plastic compounds and the risks they pose to wildlife and human health. Based on scientific results, recommendations concerning possible ways toward reducing plastic pollution in the aquatic environment should be prepared for decision-makers (water and waste management authorities, environmental protection agencies, river basin commissions, funding agencies, etc.), stakeholders involved in the plastic cycle, NGOs, and the general public in order to ensure a wider uptake of the key messages. Such recommendations can act as a catalyst for changes in policy development and implementation by providing and disseminating solutions and best practices to reduce plastic pollution at the wide regional level.

Experience sharing and knowledge exchange between local authorities and stakeholders involved in the plastic cycle (production, distribution, collection, recycling, reuse) have also an important role to foster identification of sustainable measures to reduce plastic pollution and multiply positive examples. Dissemination of good practices and knowledge transfer can be fostered, for example, via field visits to successful stakeholders involved in the plastic cycle, to showcase “live” examples on how various plastic products such as PET bottles, fishing nets, fibers, and rigid plastic waste can be transformed into high-quality raw materials. Such visits can accelerate replication of positive experiences and contribute to the reduction of pollution in new regions.

Events like science festivals and exhibitions, science books, and plastic cleaning activities also contribute to raise the awareness of people, supporting also the achievement of the United Nations Sustainable Development Goal 14 to "conserve and sustainably use the oceans, seas, and marine resources for sustainable development." With increasing ocean literacy in the society, the economic stability and security can be improved, supporting at the same time the society to understand critical issues associated with ocean-related topics such as ecology, trade, energy exploration, climate change, biodiversity, the link between ocean and human health, etc.

Interdisciplinary work, bridging different disciplines such as arts, sciences, humanities, and social sciences (Fig. 9), can also be very effective in tackling problems such as plastic pollution, with the integration of a diverse range of disciplines generally producing augmented consensus and fruitful synergistic solutions [97].

Social media campaigns play a crucial role in raising public awareness: TV, radio, Facebook, and Twitter, – they all have the possibility to reach people at broader scales, and, hence, they can mobilize wider support to curb the current pollution trends.

NGOs contribute to communication and dissemination activities by writing science books and articles, attending festivals, exhibitions, presentations, conferences, projects, TV shows on the environment, cleaning up events, and expeditions, giving interviews, education activities-school programs, and citizen science projects.

Fig. 9 Teaching future teachers about plastic pollution at Zuyd University, Netherlands. (Photo credit: Gijsbert Tweehuysen)

Within the framework of, e.g., LIFE VISPO project run by ERI, partnerships with schools, NGOs, public and business organizations, and media were developed to promote the initiatives for reducing plastics in the aquatic environment and raise attention to the stakeholders' role against pollution. A successful example for local initiatives is to be present on sport events and reach out to a larger audience who uses nature for leisure activities. This is how people from different age groups were interviewed, leading to the conclusion that most people are not aware of the plastic impact and ways to reduce plastic pollution by simple actions.

7 Conclusions: The Way Ahead

Generated in the last decades by the development of human society, plastic pollution extended gradually across the globe, turning into a significant threat to wildlife and human health.

Preliminary investigations of the impacts triggered by plastic pollution show alarming results, and, hence, urgent actions are needed to curb the pollution trends. While the stakeholders involved in plastic management can improve their cooperation to close the plastic production-reuse loop in a circular economy approach, there are also connected fields that could have an essential contribution, such as research and innovation, education, awareness raising, etc.

However, the biggest change should take place at the societal level, where multiple choices are possible to reduce plastic pollution by simple changes of the daily habits:

- Reducing the use of single-use plastic products (bags, bottles, cups, plates, food packaging, straws, etc.)
- Reusing plastic products
- Repairing, sharing, or renting devices incorporating plastic
- Supporting plastic recycling by selecting and disposing plastic waste at appropriate collection points
- Participating in actions aiming to clean plastic waste
- Selecting products from manufacturers with a higher recycling rate
- Shopping directly at local or farmers' markets to avoid unnecessary plastic packaging
- Reducing purchase of products incorporating microplastics
- Opting for promotional gifts, bags, bottles, etc. made of biodegradable products
- Buying items made of natural materials, giving preference to eco-friendly items

Reducing plastic pollution therefore requires a concerted effort from all of us – and with minor behavioral changes, we can all contribute to curb the current pollution trends and have a healthier environment.

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