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Plastic Pollution in Seas and Oceans

Challenges and Responses

CLIMATE AND SUSTAINABILITY

Konstantinos Topouzelis & Ifigeneia Tsakalogianni

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Summary

- Plastic pollution is a serious global problem, with significant environmental, health and economic impacts. The need for global action is imperative, as plastic pollution affects all levels of society and ecosystems.
- The lack of strict regulations on the production, use and disposal of plastics, as well as weak enforcement and imposition of penalties are some of the main reasons for the increase in plastic pollution.
- Implementing policies to promote the circular economy is critical, with the aim of reducing plastic waste generation and increasing recycling.
- The planning of the response to the problem requires the creation of a mechanism for observing and tracing plastics, i.e. recording the current situation in a scientific and indisputable way.
- Cost-effective solutions, such as incentives to use biodegradable materials and the development of innovative recycling methods, need to be promoted.
- Enhancing environmental education and public awareness is essential to change behaviors and promote sustainable consumption practices.
- International cooperation is needed to create common standards and rules and cooperative inspection and enforcement mechanisms, as plastic pollution is a cross-border issue.
- Governments must support research and development of new technologies to reduce plastic litter and clean up the oceans.
- Imposing taxes and fees on plastic products will reduce their use and fund initiatives to protect the environment.

- A flexible, adaptive institutional framework, stricter enforcement of laws by strengthening administrative capacity to enforce rules and imposing penalties with the cooperation of all actors involved are needed, with the common goal of reducing the “plastic footprint”.

Introduction

Plastic pollution is one of the most serious environmental problems of modern humanity, as the amount of human-made waste in the riparian and marine environment has increased dramatically in recent years (MacLeod et al., 2021). Plastic pollution in the seas and coasts is not just an aesthetic issue, but has serious consequences for biodiversity, human health, the economy and social welfare of affected countries. Plastic waste breaks down into microplastics, which pose an unseen risk as microscopic plastic particles enter the food chain through marine life and affect the food chain, resulting in impacts on human health. The impact of plastic pollution is not only limited to biodiversity and health, but also extends to economic sectors that are vital for many countries, such as tourism and fisheries. Beaches and coastal areas, which are often central elements of the tourism product, deteriorate when there is a continuous increase in plastic waste.

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The impact of plastic pollution is not only limited to biodiversity and health, but also extends to economic sectors that are vital for many countries, such as tourism and fisheries.

Numerous scientific studies highlight the extent of the problem and suggest ways to monitor plastic pollution (Andriolo et al., 2024; Cózar et al., 2021, 2024; Goddijn-Murphy et al., 2024; Guffogg, Blades, et al., 2021; Guffogg, Soto-Berelov, et al., 2021; Papakonstantinou et al., 2021; Topouzelis et al., 2019, 2021). To address the problem, international institutions have taken certain initiatives. The United Nations Environment Programme (UNEP) launched the Global Partnership on Plastic Pollution and Marine Litter (GPML) at the United Nations Conference on Sustainable Development (also known as "Rio+20", the 20-year follow-up to the historic 1992 United Nations Conference on Environment and Development in the same city) in June 2012. However, a more systematic global response to the problem came in March 2022 when the UN approved a historic resolution to establish the first international treaty on plastic pollution (UN Plastic Treaty) (UNEP, 2022), which is currently under development. Today, global plastic pollution, sustainable development, and "plastic justice" are current issues highlighted by scientific studies (Stoett et al., 2024).

The questions that emerge about tackling plastic pollution are at the heart of the academic and policy debate: first, what policies are needed at international, regional and national levels to tackle plastic pollution? What are the key elements that need to be taken into account in order for the planned policies to have the maximum effect? What is the role of states and citizens? Are there practical solutions that can be implemented and how? In order to answer these questions, the problem must be analyzed historically in order to understand its starting point, to highlight its causes and the legal frameworks that govern it. Therefore, this paper has two main objectives: first, to outline this multifaceted environmental issue, and second, to present policy proposals for addressing plastic pollution.

What are the root causes of plastic pollution?

The history of plastic pollution begins with the discovery and mass production of plastic materials in the 20th century. Bakelite was the first synthetic plastic material, discovered in 1907 by Leo Baekeland. This discovery marked a new era for industry, as plastics offered several advantages such as low production cost, durability, and lightness, quickly replacing traditional materials like wood, glass, and metal. After World War II, plastic production skyrocketed. Plastics became an integral part of daily life, with plastic bags, bottles, and food packaging dominating the market.

Plastic pollution became evident in the late 20th century when early scientific studies revealed large quantities of plastic waste along coastlines and oceans. The problem grew over the years, with international research highlighting the environmental and health impacts of plastics. It is estimated that globally, between 9 and 23 million tons of plastic enter the marine environment annually. Despite scientific discoveries, including the "plastic islands" in the Pacific Ocean found in 1997, plastics remain a fundamental part of our daily lives, continuing to degrade the environment and threatening the well-being of future generations.

The root causes of plastic pollution can be attributed to three main factors: mass production and use, the durability of plastics, and inadequate waste management.

When approaching the problem objectively, the root causes of plastic pollution can be attributed to three main factors: mass production and use, the durability of plastics, and inadequate waste management.

Plastic is a material that is in very high demand and therefore facilitates mass production. In addition, due to mass production it is becoming more and more economical, and therefore more appealing. Alternatives exist, but they either cost more or consumers are not used to them. The result is that plastics are widespread all over the planet and we are not in a position to propose alternatives immediately.

Plastics are highly durable, taking hundreds of years to break down. This same characteristic, which makes them useful in many applications, becomes a major issue when dealing with plastics as waste. Additionally, microplastics—tiny plastic particles that result from the long-term use and breakdown of plastic materials—are an alarming byproduct of plastic pollution. These microplastics have been found in every level of marine and terrestrial ecosystems, from plankton to large mammals and even humans.

Moreover, there is no comprehensive and systematic way of managing plastic waste globally. While some countries enforce strict plastic waste management, the global picture is grim. Most waste management systems, designed in the early 20th century, focus primarily on landfilling. These systems are not equipped to handle the ever-increasing volume of plastic waste. Even in many developed countries, plastic recycling remains inadequate, and new products are not designed with circular economy principles[1] in mind. As a result, most plastics still end up in landfills or are dumped uncontrolled into the environment, including land, rivers, and seas.

[1] In short, the circular economy is understood as an economic model in which waste is reduced and resources are reused by keeping products and resources in use for as long as possible. Achieving a circular economy requires structural changes in modern production and consumption patterns. See below for the definition of the concept in the European context.

What is the existing legislation at European and national level?

Since the 1970s, waste legislation has continued to evolve and be enriched both quantitatively, that is, with new political and legislative developments, as well as in terms of the range of individual sectors covered. The European Union (EU) has developed a comprehensive legal framework to tackle waste management, with a particular focus on plastics. This framework aims to reduce the environmental impact of waste and promote recycling and the circular economy. Legal measures implemented at EU level form the backbone of national waste policies in all Member States, providing a coherent approach to managing plastic waste and promoting sustainability.

Key EU legislation and policy on waste management and plastics

Reducing the environmental impact of waste generation and management was one of the first elements of European environmental policy, as already in the mid-1970s the reduction of the environmental footprint of waste was identified as a key priority at EU level, with the publication of the **Waste Framework Directive** (**WFD**)[2]. The WFD is the cornerstone of EU waste legislation, establishing the basic concepts and definitions related to waste management, including the principle of waste hierarchy: in summary, the following order should be followed when regulating waste generation and management: (a) prevention; (b) preparation for re-use; (c) recycling, (d) recovery (e.g. energy recovery) and (e) disposal[3]. Essentially, adherence to the waste hierarchy principles means that any natural and legal person who generates waste should exhaust prevention and reuse as primary principles before a product becomes waste, and then, if this is not feasible, proceed to apply the principles of recycling (preferable) and then the recovery for energy production and disposal; i.e. the discharge into water, soil, etc. of products that are now considered waste (the final stage).

The following order should be followed when regulating waste generation and management: (a) prevention; (b) preparation for re-use; (c) recycling, (d) recovery (e.g. energy recovery) and (e) disposal.

The Directive also sets out two key principles: the "polluter pays" principle, which argues that the polluter should bear the costs of remediation and environmental damage, and "Extended Producer Responsibility", which requires producers to bear the costs of managing the waste stage of the life cycle their products. For plastics, the WFD mandates Member States to adopt waste management plans and waste prevention programmes, focusing on reducing plastic waste generation and boosting recycling rates. The Directive also includes provisions on hazardous waste and separate collection of waste, with the aim of ensuring effective sorting and treatment of plastics.

The **Landfill Directive 1999/31/EC**[4] aims to reduce the environmental impact of landfilling waste by setting strict operational and technical requirements and restrictions on the types of waste that can be landfilled. For plastics, the Directive encourages their diversion from landfills through measures promoting recycling and recovery. **Directive 94/62/EC on packaging and packaging waste**[5] aims to reduce packaging waste and promote sustainable solutions, while setting specific targets for the recycling and recovery of packaging materials, including plastics. According to the Directive, Member States must put in place systems for the return, collection and recovery of used packaging to meet recycling targets, while encouraging producers to design packaging that is easier to recycle and has a lower environmental impact. Indeed,

[2] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives
[3] Para. 1 of Art. 4 WFD.
[4] Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.
[5] Directive 94/62/EC of the European Parliament and of the Council of 20 December 1994 on packaging and packaging waste.

amendments to the Directive in recent years have introduced stricter recycling targets for plastic packaging, aiming to have 55% of all plastic packaging waste recycled by 2030. **Directive 2019/904/EU**[6] (a.k.a., the Single-Use Plastics Directive) targets the ten single-use plastic items most commonly found on European beaches, which account for 70% of all marine litter in the EU, by introducing a ban on certain single-use plastic products (such as cutlery, plates, straws and stirrers), and sets consumption reduction targets for others (such as plastic food containers and cups). In addition, the Directive includes measures on product design requirements and labelling and ways to cover the costs of waste management, cleaning and awareness-raising measures to mitigate the environmental impact of products by plastic producers. In addition, Regulation **1907/2006,** known as REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals[7]), has gradually introduced various restrictions on concentrations of substances found in plastics, such as cadmium[8], toxic phthalates[9] and lead[10].

The Circular Economy Action Plan, as published in March 2020, is a structural component of the European Green Deal, aiming, among others and through a series of legal and non-legal measures it introduces, to make the circular economy the norm in the EU

In the policy field, the European Commission published its Circular **Economy Action Plan in 2015**[11], defining this concept, in which "*the value of products, materials and resources remains in the economy as long as possible, and waste generation is kept to a minimum*[12]*",* and sets targets for waste generation and management, also giving priority to plastics. **The Plastics Strategy**[13] was announced in 2018 and set targets for the recycling of all plastic packaging by 2030, while **the Circular Economy Action Plan**, as published in March 2020[14], is a structural component of the European Green Deal, aiming, among others and through a series of legal and non-legal measures it introduces, to make the circular economy the norm in the EU. In this context, the new Regulation 2023/2055 introduced strict restrictions on harmful microplastics[15].

National legislation on plastics

In Greece, plastics legislation mainly includes the transposition of European legislation into national law. **Law 2939/2001** on packaging and alternative management of packaging and other products (car tires, vehicles, waste electrical and electronic equipment, excavation, construction and demolition waste, etc.) introduces the "Extended Producer Responsibility (EPR)" in practice, with mandatory participation of producers of products in "Alternative Management Systems" (AMS). The role of the Systems is to organize the collection work after sorting, shipment, temporary storage and recovery, and for each waste stream quantitative targets are set for the separate collection of the waste and for its recovery. The operation of AMS is supervised by the Hellenic Recycling Agency (EOAN, in Greek).

[6] Directive 2019/904/EU of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment.
[7] Regulation 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH Regulation) and establishing the European Chemicals Agency.
[8] Commission Regulation (EC) No 494/2011 of 20 May 2011 amending Regulation (EU) No 494/2011; Regulation (EC) No 1907/2006 of the European Parliament and of the Council.
[9] Commission Regulation (EU) 2018/2005 of 17 December 2018 amending Annex XVII to Regulation (EC) No .../... Regulation (EC) No 1907/2006 of the European Parliament and of the Council.
[10] Commission Regulation (EU) 2023/923 of 3 May 2023 amending Annex XVII to Regulation (EC) No .../... Regulation (EC) No 1907/2006 of the European Parliament and of the Council.
[11] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Closing the loop – An EU action plan for the Circular Economy, Brussels, 2/12/2015, COM(2015) 614 final.
[12] Ibid. p. 2.
[13] A European Strategy for Plastics in a Circular Economy, COM/2018/028 final.
[14] A new Circular Economy Action Plan, For a cleaner and more competitive Europe, COM/2020/98 final.
[15] Regulation (EU) 2023/2055 of 25 September 2023 amending Regulation (EC) No 1907/2006 of the European Parliament and of the Council.

Also, a new strategy in waste management is defined with the implementation of **Law 4042/2012**, with the main objective of moving to a "European Recycling Society". In this context, appropriate measures shall be taken to promote product reuse and preparation for re-use activities, in particular by encouraging the establishment and support of re-use and repair networks; the use of economic instruments; procurement criteria and quantitative targets, while according to article 84 of **Law 4819/21** specific persons are designated as responsible for the organization and operation of AMS specifically for packaging.

Law 4736/2020 incorporates Directive 2019/904/EU and prohibits the placing on the market of certain single-use plastic products and provides for measures to reduce the use of plastic cups and food containers, while **the National Action Plan for the Circular Economy (2021)** sets out the strategies and measures for the transition to a circular economy, constituting a roadmap with a four-year duration (2021-2025) and including promotional actions for circularity in production and consumption.

The National Action Plan for the Circular Economy (2021) sets out the strategies and measures for the transition to a circular economy, constituting a roadmap with a four-year duration (2021-2025) and including promotional actions for circularity in production and consumption.

As shown above, the transition to a circular economy is a key priority at EU level and a constantly evolving and multifaceted policy area. The European Commission has implemented a dense set of policy and legislative initiatives that aspire to contribute towards systemic change of existing "linear" models and drastic reduction of waste. The process is dynamic and complex, while its legal aspects as well as its interaction with EU climate objectives and the national legal framework of Member States will be at the heart of EU policy in the coming years.

What kind of policies are needed?

The policies that need to be implemented to further combat plastic pollution should take into account five key elements. **The first is that plastic as a material is not responsible for the environmental degradation, but rather its use**. Policies should aim to correct the logic of improper use by the user-consumer and consider legislative initiatives that would make the use of plastic unprofitable unless certain environmental conditions are met. Additionally, policies should consider the state's responsibility for waste collection and management, ensuring the proper removal of plastics from the environment.

Plastic as a material is not responsible for the environmental degradation, but rather its use

The second element is that plastic is a highly durable material with many properties that make it appealing, and there is no large-scale, reliable alternative. The most significant advantage of plastic in the modern world is its cost, as it is the cheapest material used in a wide range of products. Therefore, the economic dimension of plastic use makes it more appealing compared to many other solutions. Addressing plastic pollution could be achieved if the material's cost were higher than that of alternatives or if alternatives provided greater value to the product. For example, if the environmental impact cost, as well as the costs of collection, reuse, or disposal, were added to the material, its main advantage would vanish. Moreover, innovative solutions, often developed by small and emerging businesses, should be considered. These businesses tend to directly address the problem but require substantial funding to scale their projects.

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The third element concerns the lack of precise and scientific information about plastic pollution on a global scale. In other words, we do not truly know the extent of the problem that needs to be addressed. The exact amount of plastic (in metric tons) produced by industries each year is not clearly defined, as there is no mandatory recording of the quantities and products created annually. As a result, tracing these plastics is not possible. The quantities of plastic collected, recycled, and reused are also based on estimates, which are often far from reality. Therefore, current policies aim to "significantly reduce" plastic pollution, but they lack measurable goals. The consequence of this information gap is the inability to assess the effectiveness of the legislation. Essentially, we are creating policies without being able to determine whether they are solving the problem or to what extent.

The exact amount of plastic (in metric tons) produced by industries each year is not clearly defined

This brings us to the fourth element, which concerns the rigidity and complexity of the legislative framework, as well as its ineffective implementation. Despite positive initiatives at the European level, inconsistent application of waste management regulations—such as in Greece, which has been before the European Court of Justice numerous times over waste-related cases (Pouikli et al., 2024)—and differing approaches between countries make it difficult to develop a unified strategy to address the problem holistically. On an international level, the ability to regulate the global flow of plastic waste is drastically reduced due to significant gaps and inefficiencies in enforcement, as well as the inability to impose penalties severe enough to prevent environmental crimes particularly in regions with less stringent regulations, such as parts of Asia, Africa, and Latin America. On the other hand, the complexity of mechanisms, constant amendments to the legal framework, over-regulation, and bureaucracy lead to the opposite of the desired outcome.

The ability to regulate the global flow of plastic waste is drastically reduced due to significant gaps and inefficiencies in enforcement, as well as the inability to impose penalties severe enough to prevent environmental crimes

The fifth element is the widespread belief that combating plastic pollution is an issue that does not directly concern the individual and that its management is exclusively a state matter. This perception creates a gap in responsibility, where citizens tend to forego their own contribution to reducing plastic pollution, assuming that the measures and policies implemented by governments are sufficient enough to solve the problem. However, this approach overlooks the crucial role of individual action in the overall effort to address the issue. Citizen participation is essential for the success of national and international initiatives. Reducing plastic use, promoting recycling, avoiding plastic waste disposal, and supporting sustainable practices and products should all be individual actions. At the same time, individual actions will amplify social pressure for stricter legislative measures and the implementation of more ambitious environmental policies. Therefore, addressing plastic pollution requires a coordinated effort that integrates individual responsibility with collective actions at both the national and global levels.

How should we tackle the problem of plastic pollution on a practical level?

On a practical level, tackling plastic pollution is complex. It must be based on the following three-pronged approach: first, we reduce plastic use to the greatest extent possible; second, we inform and educate citizens about alternatives; and third, we establish a system for monitoring plastic pollution.

A comprehensive strategy to tackle the problem includes five pillars – objectives that must be developed simultaneously and equally:

1. Limit the creation of new plastic products and restrict the use of existing products,
2. Universal design of new products containing plastics in the context of the circular economy,
3. Collection, reuse, recycling and, exceptionally, if all the previous possibilities are not possible, landfilling (or, under strict conditions, incineration) of existing plastics on the basis of waste management principles,
4. Information and education on plastic pollution; and
5. Establishment of a mechanism for the observation and tracking of plastics.

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The policy mix to be implemented varies from country to country depending on its level of awareness and level of organization.

On a practical level, tackling plastic pollution is complex. We must implement policies that reduce the problem, specifically by industry category, by providing financial incentives to companies that do not use plastics in their products or design them in a way that the plastics used can be reused.

It is a fact that limiting the production of new plastic products is the most important factor in addressing the problem. If we want to tackle the issue at its root, we must address it at the source. **The first practical step is to limit or even eliminate plastics that cause environmental problems at their source**. The universal ban on the use of plastics in production theoretically solves the problem immediately, at least for future generations. In the hypothetical scenario where international legislation bans the creation of new plastic products, this would mean that plastic pollution production stops suddenly, but a series of new problems may arise, potentially greater than the ones we are trying to solve. The most recent example is the use of masks during the COVID-19 pandemic, which saved millions of lives. In reality, we cannot immediately and safely replace products that use plastic as a raw material, as it is a widespread material with multiple benefits. However, we must implement policies that reduce the problem, specifically by industry category, by providing financial incentives to companies that do not use plastics in their products or design them in a way that the plastics used can be reused. Additionally, the cost of creating plastic products should include a tax burden (e.g., per metric ton) that accounts for the lifecycle costs of plastic products, including tracking, collection, reuse, transport, or disposal (landfill), and certainly the environmental costs they impose.

New products must first demonstrate that they are based on the principles of the circular economy to be licensed and released in the market.

The second practical step in a comprehensive policy to tackle plastic pollution is the universal design of new products containing plastics within the framework of the circular economy. The circular economy, as mentioned earlier, is an economic model aimed at sustainable resource management and minimizing waste. Unlike the traditional linear economic model ("produce, consume, discard"), the circular economy promotes recycling, reuse, repair, and refurbishment of products to keep them in the economy as long as possible. Designing plastic products with their environmental footprint in mind throughout their entire life cycle is essential and relatively easy to implement. Legislators must define the goals to be applied throughout the product's life cycle, and businesses must design their products in ways that do not burden the environment or future generations. New products must first demonstrate that they are based on the principles of the circular economy to be licensed and released in the market. Then, through a monitoring mechanism, any deviations will be flagged, and industries will bear the cost of bringing their products back into compliance with the original goals. The circular economy model adds value to combating plastic pollution and clearly indicates the responsibility of the product manufacturers toward the environment.

In order to tackle plastic pollution, particular mention should be made of the need for innovation by new technologies ("disrupted technologies") which play a crucial role. These technologies disrupt traditional methods and practices and introduce innovative

materials and processes that can reduce or even eliminate the need for conventional plastics. A prime example is the development of biodegradable materials produced from plant raw materials, which offer a sustainable alternative to traditional plastics. At the same time, cutting-edge technologies such as artificial intelligence and machine learning are being used to improve recycling processes and monitor the flow of plastic pollution. Through advanced algorithms, recycling facilities can improve material separation and increase recovery rates, while allowing accurate mapping of pollution globally. The use of these technologies is very important to address the problem and the need to adopt such solutions is imperative.

Cutting-edge technologies such as artificial intelligence and machine learning are being used to improve recycling processes and monitor the flow of plastic pollution.

The first two practical measures to tackle plastic pollution address the problem for generations to come. They follow the basic principle of reducing the amount of plastic entering the environment at its source. They aim to reduce the quantities of plastics that we will have to manage in the future, but they do not address the problem directly, i.e. in its current state. However, addressing the problem in its current state in practice requires measures related to the "classical" environmental theory of reusing, recycling, collecting and, if all the previous possibilities are not possible, disposing (or, under strict conditions, incinerating) existing plastics. The rationale for approaching the problem in this case is to reduce the environmental impact of plastics, usually through government structures.

The third practical measure to address plastic pollution is twofold: initially, it involves the creation of structures that facilitate the practical handling of the problem, and, secondly, it shifts the cost of implementing services from local governments to the businesses that produce the plastics. The creation of structures for recycling and reuse is extremely important and relatively simple. One can look at Northern European countries as an example, where the problem has been addressed through specific waste streams and businesses whose business models are based on the reuse of materials. The implementation of these systems, even on a national level, is purely a matter of planning and resources. The limiting factor is resources, which, for the most part, come from government funding. In other words, the state is called upon to cover the environmental burden caused by plastic products within its territory. The policy response should be the creation of recycling and/or reuse structures by the creators/owners of the pollution sources or the companies that use plastic products. The primary responsibility here lies with the large or very large companies that dominate the market and are responsible for the largest amounts of plastic being circulated in each country. A policy of mandatory tracking and recycling mechanisms for these companies' products is essential and is expected to bring about structural changes in addressing plastic pollution. For example, a soft drink (or cosmetics or car tire) company would be required to track its waste and create recycling mechanisms.

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For the immediate handling of the problem, in addition to recycling and reuse, there remains the question of what to do with the existing plastics that cannot be recycled or reused. The answer is straightforward: landfill or (under strict conditions) incineration. Both solutions have advantages and disadvantages. The policy of using either method depends entirely on scientific knowledge and expertise. In cases where the conditions for incineration are fully met and the environmental impacts (e.g., air pollution) are minimized, the benefit of reducing the volume of waste is a significant factor that should be taken seriously. Burial and incineration are the final stages of the plastic pollution management chain. However, perhaps the most important unanswered aspect is the collection of existing plastics, which requires a unique mix of policies.

Plastic collection follows the logic of waste collection. In many countries, separate waste streams (e.g., paper, glass, aluminum, and plastic) exist. The policy of separating waste streams at the source, i.e., at the consumer level, has proven to be the most cost-effective and environmentally friendly. Therefore, the design of regular plastic waste collection on a national level is deemed most appropriate. However, a major problem exists with the collection of plastic waste that is not easily accessible, such as plastics on beaches, on the surface, and at the bottom of the sea. The problem in these cases is that plastic waste is not concentrated in one location, making it difficult to collect, and it is often fragmented into many small pieces, further complicating the process. These types of plastic waste result from incorrect disposal by users and create the greatest environmental problem highlighted in recent years.

Addressing the collection of such plastics is extremely difficult as it requires significant human resources and logistical infrastructure. The proper approach starts with identifying problem areas and then collecting the waste. For example, in a country like Greece, with over 16,000 kilometers of coastline, it is imperative to know the areas where cleanup efforts should be focused. At the same time, the issue of plastic waste at the bottom of the sea requires specialized planning to predict the areas with large amounts of plastic waste and specialized equipment to collect it. The cost of collecting this plastic is very high and requires specialized knowledge. Tackling this dimension of the problem requires national collection policies based on specific goals, such as identifying and collecting x tons of plastic in each municipality, along with adequate funding. All relevant stakeholders, particularly at the local level—such as regional authorities, local governments, businesses, NGOs, and active citizens—can participate in the collection. This measure is especially valuable when combined with the fifth pillar, namely the system for recording and monitoring plastic pollution.

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For effectively tackling plastic pollution, **the fourth practical measure involves widespread public awareness and education**. It is essential to inform citizens about the consequences of plastic pollution and the practices they can adopt to reduce it. A comprehensive and multi-level policy approach is needed, based on education and awareness programs in schools, national public campaigns through mass media and social networks, educational programs for adults, rewards for and promotion of alternative solutions and good practices, and collaboration between NGOs, environmental organizations, and scientific bodies specializing in environmental education and awareness. These programs should have specific performance indicators and follow a continuous evaluation and updating process to ensure their effectiveness and adaptability to evolving needs. New technologies and communication media, such as mobile apps, virtual reality, and online courses, should be incorporated to inform the public. A policy of an integrated approach to awareness and education against plastic pollution will create a strong foundation for educating the public, leading to a demand for fundamental changes in consumer, business, and government behaviors and practices.

A policy of an integrated approach to awareness and education against plastic pollution will create a strong foundation for educating the public, leading to a demand for fundamental changes in consumer, business, and government behaviors and practices.

Finally, **the fifth practical measure relates to the creation of a national mechanism for observing and tracking plastics**. None of the above measures will be of much value if we do not know their effectiveness. This means that planning to address the problem starts with recording the current situation in a scientific and indisputable manner so that we understand the extent of the problem. This is followed by goal-setting, i.e., setting the target we want to achieve and the time frame estimated for its achievement. Then, the aforementioned measures follow, which are continuously evaluated to determine their level of effectiveness. The information collected and recorded should be available

to the general public, free of charge, easily, and immediately. The measure of creating a mechanism for monitoring plastic pollution, especially in problematic areas such as beaches and the seabed, requires high expertise and a combination of multiple data sources. The scientific community, along with companies specializing in the field, should meet this need to record the extent of plastic pollution in its current state and monitor it adequately in the future. The combination of multiple reliable measurements and new technologies, such as artificial intelligence, "smart" recording cameras, aerial photography observation, or underwater sensors, are undoubtedly tools that must be used in this direction.

The tracing of plastics, i.e. the mechanism by which the origin of plastics can be identified (and therefore the materials of which they are composed, their additional substances, the year and country of origin, the manufacturing company and the respective products) is one of the most important actions to tackle plastic pollution. However, for the industry, it is a groundbreaking endeavor with high costs and business risks. By tracking plastic pollutants, we will be able to recognize their origin and therefore link a company's product to the pollutants it produces. Despite the seemingly negative attitude of industries to comply with such a measure, it is the only path to monitor plastics and quantitatively assess pollution by industry category. This information is extremely useful for understanding the journey of plastics, evaluating the implementation of measures (e.g., recycling, reuse, collection), quantifying failures, gaps, and the complexity of legislation, and redesigning the process with measurable goals. The tracking information should not have a negative connotation for companies, nor should it serve as a basis for fines. On the contrary, it should be used by the companies themselves, within the framework of the circular economy, to examine the fate of their products and take measures for their better future use. The combination of a plastic pollution observatory and plastic product tracking is certain to bring about a significant change in the perception of the problem and, consequently, in its resolution.

The tracing of plastics, i.e. the mechanism by which the origin of plastics can be identified is one of the most important actions to tackle plastic pollution.

Why Greece has an advantage in tackling plastic pollution

All scientific studies show that Greece is a country threatened by plastic pollution and is certainly not exempt from this problem. Plastics are found in abundance on the country's coasts and seabed and constitute a significant environmental pressure that affects the well-being of both its citizens and visitors. The extent of the problem is clearly illustrated by multiple reports, studies and measurements in Greece. The Hellenic Centre for Marine Research (HCMR) systematically monitors and records plastic pollution according to the relevant EU monitoring guide, and the number of plastic pollutants it records far exceeds the international limits of good condition of beaches. At the same time, the "Typhoon" program of the A. C. Laskaridis Public Benefit Foundation, which uses a 72-meter ship to clean up the country's remote coasts, has cleaned more than 3,240 beaches and removed more than 580 tons of litter for the period 2019-2023. Similarly, the Coastal Zone Marine Litter Observatory, first developed at the Department of Oceanography and Marine Sciences of the University of the Aegean and which uses aerial photographs and artificial intelligence to detect and monitor coastal pollution in the country, has recorded over 90 km of Greek coastline with increased plastic pollutants throughout the observation area.

However, Greece holds a significant advantage in tackling plastic pollution. The country can implement the aforementioned policies on small, remote islands, which, due to their size and environmental awareness, can adapt to the required changes. There are

already examples of "green" islands in Greece that are successfully addressing environmental challenges. Some islands have also piloted many of these measures, with immediate results in combating plastic pollution. One prominent example is the European LIFE DEBAG program (2015-2019) (https://www.lifedebag.eu/), where plastic bag pollution on the island of Syros was significantly reduced through targeted actions and interventions, guided by the University of Patras.

Greece holds a significant advantage in tackling plastic pollution

Addressing the progressive increase in plastic waste through these policies becomes much easier when the area of implementation is small, such as on an island with a defined population. This ease of implementation stems from a key factor: the issue of plastic pollution becomes personal to the local citizens, rather than being seen as a general societal problem. The residents stop relying solely on state policies to tackle the issue and begin taking personal measures to contribute to the solution. In other words, the mindset of the inhabitants changes, and the problem becomes personalized—owned by each individual. For instance, people reduce their use of plastics to the greatest extent possible, purchase products that incorporate the principles of the circular economy in their design and production, and maximize the reuse and recycling of plastics. At the same time, informational events and campaigns are organized, and local plastic pollution is more easily identified. The adoption of good practices becomes a matter of time for neighboring regions, creating a framework for regional pollution control, which will gradually lead to a national strategy for addressing the problem.

This ease of implementation stems from a key factor: the issue of plastic pollution becomes personal to the local citizens, rather than being seen as a general societal problem.

Conclusions

Policies to combat plastic pollution can be thus summarized in five key assumptions:

- The environmental degradation caused is not due to plastic as a material itself, but rather its usage.
- There is no reliable large-scale alternative, as plastic is a highly durable material with multiple appealing properties.
- There is a global lack of precise and scientific information regarding the scale of plastic pollution.
- Legal hurdles, the complexity of the legislative framework, inefficient implementation, weak enforcement of penalties, and differing approaches between countries hinder the formation of a unified regulatory strategy for waste management.
- The prevailing belief is that plastic pollution is not an issue that directly concerns every individual but should be managed at the state level.

In this context, it is clear that the problem of plastic waste management is multifaceted and requires cooperation at all levels of society, from individual citizens to the state and lawmakers. Greece serves as a characteristic example where, despite the proper adoption of EU environmental legislation (albeit often delayed), its implementation faces shortcomings. The complexity of the legal framework, lack of resources, and slow administrative processes hinder effective waste management, particularly for plastics, allowing issues like illegal landfills and plastic dumping into the sea to proliferate. Additionally, economic pressures and a lack of reliable monitoring mechanisms often lead to bypassing the legal (but bureaucratic) administrative processes. The fines from the European Court of Justice for violations of environmental waste directives are frequent, while the issue is further exacerbated by the reluctance of citizens to participate in recycling and responsible waste management. Despite legislative reforms,

practical application remains a challenge, and public awareness is deemed crucial to solving the problem.

Legislative adjustments to keep pace with the rapid growth of the plastics market are necessary, as clear and binding rules

A comprehensive strategy to address this issue includes, as previously mentioned, five specific pillars—objectives that must be developed simultaneously and equally, involving several practical measures: a) limiting the creation of new plastic products and the use of existing ones, b) designing new plastic products within the framework of the circular economy, c) organized collection, reuse, recycling, and—under strict conditions—landfilling or incineration of existing plastics, d) public education and awareness campaigns, and e) the establishment of a mechanism for tracking and monitoring plastics.

Alongside the gradual establishment of mandatory environmental "safety nets" and technical specifications that promote the circular economy. Incentives (mainly of financial nature) should also be introduced.

However, without the swift adaptation of the legal framework to technological requirements, appropriate responses to cross-sectoral policy proposals, and strengthening of the administrative system with trained personnel, these objectives cannot be achieved as urgently as the current situation demands. The regulatory framework plays a critical role in shaping a stable and clear structure for managing plastic pollution, ensuring the compliance of all stakeholders, from producers to consumers. Legislative adjustments to keep pace with the rapid growth of the plastics market are necessary, as clear and binding rules for limiting plastic production and use are required, alongside the gradual establishment of mandatory environmental "safety nets" and technical specifications that promote the circular economy. Incentives (mainly of financial nature) for recycling and reusing plastics should also be introduced.

It is essential for the institutional framework to become more flexible and adaptive, incorporating tracking and monitoring technologies for plastics, as proposed in the five pillars. At the same time, an effective solution to plastic pollution requires strengthening regulatory measures by introducing the concept of the "life cycle" of plastic—tracking costs, collection, reuse, transport, or disposal (landfill)—to clearly demonstrate the highly burdensome nature of this material, both economically and environmentally. Stricter limits could be established for the production of new plastic products, with incentives for using alternative, more environmentally friendly materials. Furthermore, stricter enforcement of laws, including systematic penalties and fines for violators, is necessary to deter frequent non-compliance. The creation of a robust central regulatory body with regional branches and the speeding up of penalties will enhance the effectiveness of regulations and serve as a deterrent for those who do not comply, contributing to a significant reduction in plastic pollution. This combination of factors can improve the effectiveness of policies against plastic pollution, ensuring that targets set are not just theoretical but implemented in practice.

The solution is neither simple nor obvious; it requires systematic cooperation between citizens, the state, lawmakers, and the private sector

Ultimately, the solution is neither simple nor obvious; it requires systematic cooperation between citizens, the state, lawmakers, and the private sector, with an emphasis on public awareness, active participation, and the realization of the broader benefits that will arise from reducing the "plastic footprint" in Greece

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