



Adoption and diffusion of marine litter clean-up technologies across European seas: Legal, institutional and financial drivers and barriers

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ABSTRACT

This study reviews existing legal, institutional and policy tools and frameworks, relevant to the introduction and adoption of new marine litter clean-up technologies in two regional European seas, the Mediterranean and the Baltic. A combination of desk studies in six countries bordering the Baltic (Estonia, Germany, Sweden) and the Mediterranean (Greece, Italy, Tunisia), and interviews with experts and stakeholders, is used to identify key drivers and barriers to the adoption and diffusion of marine litter technologies. The main conclusion of the study is that the most influential pieces of legislation relevant to marine litter management are top-down EU policies, often forming the basis of regional and national plans. Moreover, the study finds that several drivers of marine litter technologies may at the same time be critical barriers. These factors include public awareness, consumer behaviour, enforcement of legislation, and the rise of SMEs engaged in recycling and eco-labelling of marine litter.

1. Introduction

Marine litter is one of the key indicators in the European Marine Strategy Framework Directive (MSFD) to assess Good Environmental Status for all European seas and monitor the effectiveness of policy measures (Galgani et al., 2013). It poses a complex and multi-dimensional environmental challenge that involves human activities (e.g. industry, urban waste, tourism, maritime traffic) as pollution sources, as well as physical processes (e.g. ocean currents, waves, wind) that control the fate of litter in the marine environment. The presence and accumulation of plastic litter specifically has been recognized as a major environmental problem due to its negative impacts on marine ecosystems and ecosystem services (Beaumont et al., 2019; Law, 2017). Globally the amount of litter entering the oceans in 2010 has been

estimated at between 4.8 and 12.7 million tons for plastics alone, with 275 million tons of plastic waste generated in 192 coastal countries in that specific year (Jambeck et al., 2015). Plastics enter the marine food web through ingestion by marine organisms, and there is growing concern for the potential consequences in the marine environment for human food security, food safety and health (Barboza et al., 2018; Leslie and Depledge, 2020; Vethaak and Leslie, 2016). With an estimated increasing trend in production of 5% per year, an additional 33 billion tons of plastic will have entered the oceans by 2050 if no action is taken (Rochman et al., 2013).

The social costs of marine litter in different economic sectors are substantial (Beaumont et al., 2019; Brouwer et al., 2017; Mouat et al., 2010; UNEP, 2016a), leading to a high level of interest in Europe and elsewhere in the clean-up, prevention and mitigation of litter. There has

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been a spur in research into marine litter sources, pathways and effects over the past decades, increasing from fewer than 40 publications per year in 1995 to over 200 in 2013 (Ryan, 2015). At the European level, the European Marine Observation and Data Network provides an important platform that facilitates the collection and sharing of data, including on marine litter (Molina Jack et al., 2019).

Research is also growing with regards to the implementation of marine litter legislation. A recent study assessing 52 relevant European projects (Maes et al., 2019) which researched or contributed to the implementation of European marine litter legislation, shows that Western European countries have contributed more to marine litter research and therefore received more funding, which has resulted in a concentration of scientific capacity by topic and countries. The study shows at the same time the importance of having access to European financial instruments like INTERREG, LIFE, and Horizon 2020 to support large scale environmental projects.

The Horizon 2020 funded project CLAIM (Cleaning Litter by developing and Applying Innovative Methods in European seas) aims at providing practical tools for the mitigation and efficient management of marine litter in the Mediterranean Sea and Baltic Sea. The project is doing so by first developing and then demonstrating cost-effective cleaning methods for plastic waste, in situ, as near as possible to the major sources of marine litter, such as coastal areas, and by developing technologies to limit the amount of litter entering the sea, for example through wastewater treatment facilities. CLAIM addresses both macroplastics (i.e. plastic pieces larger than 5 mm that are visible to the naked eye) and microplastics (i.e. plastic pieces smaller than 5 mm that are not visible to the human eye). To facilitate technology development, identify implementation barriers and understand potential scaling mechanisms, it is important to also identify existing legal and policy frameworks, as well as relevant available investment tools, funds and incentives. Moreover, it is key to determine whether these legal and policy frameworks support or act as barriers to the introduction of new marine litter management technologies.

The main objective of this article is to present and discuss the current relevant legal and policy frameworks, including financing instruments, in selected case study countries bordering the Baltic Sea (Estonia, Germany and Sweden) and the Mediterranean Sea (Greece, Italy and Tunisia), where new marine litter clean-up technologies are piloted. The main focus of this article is to discuss the creation and implementation of European and national policies, rules and regulations that support the development, adoption and diffusion of technical measures to remove or prevent marine litter from entering the marine environment. The sample countries are mainly EU members, with the exception of Tunisia which was included as a non-EU country bordering the Mediterranean Sea. The study is based on a combination of national and international literature reviews and expert and stakeholder consultations. A semi-structured interview protocol was developed and used to interview 27 national and regional experts and stakeholders and gauge their opinion with respect to the current situation in their countries, as well as drivers and barriers underlying the implementation of the existing national and regional policy frameworks.

2. Governance of marine litter pollution

Littering of our oceans is a transboundary issue in view of the fact that nearly two thirds of the ocean's area lies beyond national jurisdictions, and has become the new tragedy of the commons (Vince and Hardesty, 2018). As marine litter does not obey national borders or jurisdictions, the issue of enforcing responsibility is particularly challenging. At present there are many local, national, and international strategies in place. National interventions are widespread in Europe, and they are increasing in Africa, Asia and Oceania, but they are limited in North America and are severely lacking in South America (Xanthos and Walker, 2017).

International efforts include the Global Partnership on Marine Litter

(GPML), the UNEP Honolulu strategy and CleanSeas campaign, and the G7 Action Plan to Combat Marine Litter (Magnusson et al., 2016). Unfortunately, none of these strategies have created an effective global structure and commitment, the only exception being Annex V of the international agreement MARPOL, which bans ships from dumping litter at sea (Borrelle et al., 2017). However, the latter has not proven to be very effective in reducing marine litter emissions because 80% of litter originates from land-based sources, and due to a relatively low level of compliance (Magnusson et al., 2016). In January 2021, the Basel Convention¹'s Plastic Waste Amendments entered into force so they are now mandatory for 186 countries and the European Union. The Amendments clarify the way plastic waste is internationally traded, bringing additional types of plastic waste into the existing Prior Informed Consent (PIC) Procedure, a mechanism to control transboundary movements of hazardous and other wastes. The Amendments also specify measures to support implementation of this legislation, especially in developing countries. At the European level, the issue is being addressed through Regional Sea Conventions, such as the UNEP/MAP - Barcelona Convention,² HELCOM,³ OSPAR,⁴ and the Black Sea Commission - Bucharest Convention⁵ (Vince and Hardesty, 2018).

All in all, the global governance of marine litter is fragmented, with uneven regulations in different countries, uncoordinated policies, and weak international institutions (Dauvergne, 2018; Stoll et al., 2020; Tiller and Nyman, 2018). As a result, the need for a new international legal instrument or treaty with global reduction targets and plans has been identified as a major opportunity to drive the change required to overcome this problem (Borrelle et al., 2017; Chen, 2015; Dauvergne, 2018; Gago et al., 2020; Haward, 2018). The Montreal Protocol adopted in 1987 to eliminate ozone-depleting substances (chlorofluorocarbons) worldwide has been referred to as a best-practice multilateral agreement example to increase public awareness and solve global environmental pollution problems (Haward, 2018). Such an international agreement for marine litter should work towards achieving a circular economy, implementing an extended producer responsibility program, and creating a global fund that can be used by member states, especially developing economies, to improve waste management infrastructures (Borrelle et al., 2017). However, if any lesson can be learned from such global policy negotiations, including the 1994 UN's Framework Convention on Climate Change (UNFCCC), it is that these multilateral agreements can take a lot of time (more than 20 years in the case of the UNFCCC) and face significant hurdles in implementation. Since there is no time to waste, a suggestion has been made to incorporate plastic pollution into the ongoing negotiations related to the conservation and sustainable use in areas beyond national jurisdiction (BBNJ) under the UN Convention of the Law of the Sea (Tiller and Nyman, 2018).

In the meantime, international coordination of existing policies is required (Stoll et al., 2020). For some types of litter, e.g. microplastics, substantial removal from the environment is not yet feasible (Law and Thompson, 2014). Therefore, a transition to a more circular economy response seems crucial to govern the production, use, and disposal of products that would otherwise become marine litter, as well as the removal of litter from the oceans (Löhr et al., 2017; ten Brink et al., 2018; UNEP, 2016b). Currently, the governance of packaging, the single biggest source of macroplastic pollution, is considered weak and uncoordinated, while there is effectively no governance at all of the two

¹ Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.

² United Nations Environment Programme/Mediterranean Action Plan – Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean.

³ Baltic Marine Environment Protection Commission.

⁴ Convention for the Protection of the Marine Environment of the North-East Atlantic.

⁵ Bucharest Convention on the Protection of the Black Sea against Pollution.

biggest sources of microplastic pollution, i.e. synthetic tyres and clothing (Dauvergne, 2018).

The costs of marine litter pollution are usually not borne directly by the producers or the polluters (Gago et al., 2020), and this has been considered the root of the problem of litter accumulation in the oceans (Bergmann et al., 2015). Extended producer responsibility programs, where the environmental cost of products throughout their life cycles are integrated into their market prices (Borrelle et al., 2017) are one way to address this 'market failure'. There is also potential to reduce the amount of marine litter through a combination of market-based instruments (environmental taxes, direct payments, deposit-refund schemes etc.) (Oosterhuis et al., 2014), infrastructure for waste disposal improvements, and entrepreneurial ventures and technological innovations (Dijkstra et al., 2020, 2021).

Even if effective measures are implemented by state actors, the importance of non-state actors cannot be overstated (Vince and Hardesty, 2017). It is important here to consider voluntary initiatives by business and industry, which may be effective, but also suffer from a lack of accountability and legitimacy (Dauvergne, 2018; Gago et al., 2020). Civil society action is of particular importance, including specific initiatives connected to market and economic drivers, such as creating awareness with citizens and lobbying with governments, citizen science, beach clean-ups and single use plastic bans led by Non-Governmental Organisations (NGOs). Consumer demand can also force reductions in the level and type of plastic pollution (Haward, 2018). In addition, communities and other non-state actors like consumers play an important role in driving social change, providing a social license to operate, and initiating changes to corporate policies and products (Vince and Hardesty, 2018).

3. Methods and materials

To describe and analyse the current legal, institutional and financial drivers and barriers for the adoption and diffusion of marine litter clean-up technologies across European seas, a mixed research methodology was used in this study. First, a desk-based analysis was carried out of national legal and policy frameworks addressing marine litter management, in a selection of countries (Estonia, Germany and Sweden surrounding the Baltic Sea and Greece, Italy and Tunisia surrounding the Mediterranean Sea). Second, a series of semi-structured interviews were held with national and regional stakeholders. These methodological components are described in more detail below.

The desk-based analysis has been undertaken by the authors who have knowledge of the countries in focus, and the relevant linguistic skills. The aim of this analysis was, firstly, to develop an overview of existing legal policy frameworks of relevance to marine litter management, and to identify which of these may provide a regulatory driver or barrier to the implementation and uptake of different marine litter clean-up technologies. Secondly, the team also identified investment tools, funds and incentives which could financially support the development and implementation of marine litter clean-up technologies. National policy documents, including legislation, overarching policy strategies, action plans, MSFD Programmes of Measures, etc., were identified by searching national regulator and agency websites and national regulatory databases. The former was also used to identify available investment tools, funds and incentives relevant in the respective case study country. Wider website searches were carried out to complement the information identified via state websites, in particular to provide further insights into investment opportunities for marine litter clean-up technologies.

The identified pieces of national legislation and policies relevant to marine litter clean-up technologies were subsequently described and analysed in terms of how they might drive or support, or perhaps pose a barrier to, the implementation and uptake of marine litter clean-up technologies. Here, a distinction was made between technology types, i.e. technologies focused on the collection of marine litter, the

processing or transformation of marine litter, and treatment of microplastics in wastewater. Relevant investment tools, funds and incentives are described, including an explanation of how they might be accessed to financially support the development and implementation of different types of technologies.

The second phase of the mixed methods study involved semi-structured interviews with regional and national experts and stakeholders. These interviews were used to supplement the desk study overviews and to identify key stakeholder opinions about drivers of and barriers to the implementation of existing policy frameworks for marine litter management in the mentioned countries. First, a long-list of relevant stakeholders was developed, including representatives from national and international organisations with unique knowledge and understanding of the challenges posed by marine litter management across European seas. Stakeholders and experts were added to the list based on geographical scope (having experience relevant to the studied countries), institutional representation (governmental, non-governmental, research, industry and business) to ensure stakeholder diversity, and knowledge of different marine litter clean-up technologies. Based on this list, 50 experts and stakeholders were contacted for interviewing, avoiding where possible overlap in institutional or geographical scope. Simultaneously, a semi-structured interview protocol was developed to guide the interviews (see the supplementary material). The interview protocol started with a short introduction to the different technology types, followed by introductory questions about the interviewee's current position and experience with marine litter management, and questions specifically related to existing legislation, policies, and their opinions and perceptions of drivers and barriers to the development, adoption and diffusion of marine litter technologies. The survey was further tailored to each interviewee's specific area(s) of expertise, with interviewers asking additional questions to follow up on specific points of interest that arose during each interview. For example, academic experts were asked about research and the status of scientific knowledge in their field and decision makers were questioned about the local and national policies that they designed and implemented.

The interviews were carried out either face-to-face or remotely by phone or online video conferencing software (Skype or Zoom). Interviews typically lasted under 1 h. A summary of each interview with notes was prepared by the interviewer and stored on a secure collective drive only accessible to the team members. The data contained in these summaries were analysed by the first author, without the use of coding software, to look for similarities and differences, find common themes and develop categories, particularly related to drivers and barriers of the adoption and diffusion of marine litter technology. The results of the analysis were subsequently verified with the other authors who had conducted the interviews.

In total 27 of the 50 stakeholders and experts identified and contacted agreed to be interviewed, yielding a response rate of 54%. Most refusals to participate were related to a lack of time and other obligations and commitments, especially in the private sector. Note also that some of the interviews overlapped with the start of the pandemic, making it extra challenging for several invited interviewees to make themselves available for the interview. The anonymized list of experts and stakeholders, the organisations they represent and their roles is presented as supplementary material in the Appendix to this paper. Most of the interviewees work in academic research (22%), followed by small and medium enterprises (SMEs, 19%), national governments, international organisations and consultants (each 11%). The representation of the stakeholders is visualized in Fig. 1. Some degree of self-selection bias and hence in representativeness exists because stakeholders from the plastics industry declined to participate in the interviews.

4. Results

The primary pieces of legislation relevant to marine litter management in the European countries bordering the Baltic and Mediterranean

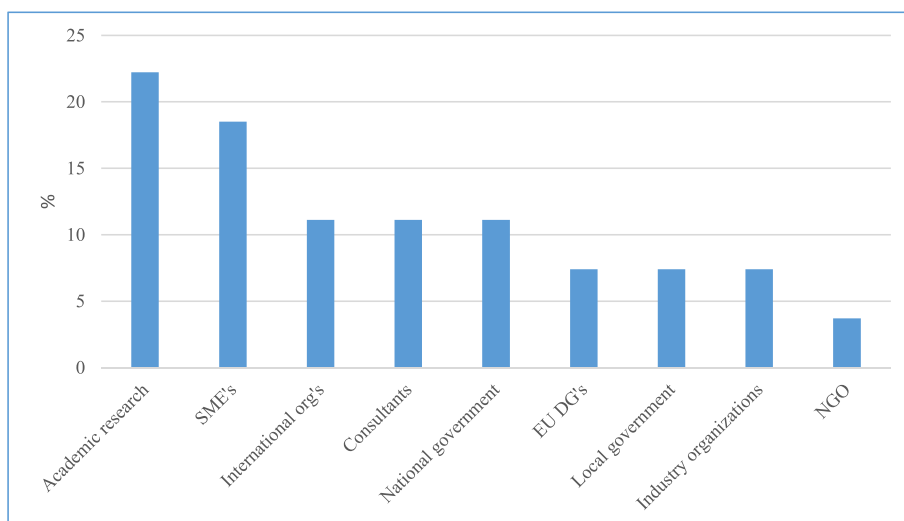


Fig. 1. Distribution of institutional affiliations of the stakeholders and experts interviewed.

Note: EU DG's: European Directorate-Generals. International org's: international organisations. SME's: small and medium enterprises. NGO: non-governmental organization.

Sea are top-down measures developed at the EU level. The measures include the Marine Strategy Framework Directive (MSFD) (2008/56/EC), the EU Waste Framework Directive (2008/98/EC), the European Strategy for Plastics in a Circular Economy, the Single Use Plastics (SUP) Directive (2019/904/EU), the Port Reception Facilities Directive (2019/883/EU) for the delivery of waste from ships, and the Urban Wastewater Treatment Directive (91/271/EEC). Also relevant are the Water Framework Directive (WFD) (2000/60/EC) and Directive 2014/90/EU on marine equipment. The transposition of some of this high-level European legislation into national regulation and policy is still pending. However, these directives and policies are the basis of various regional and national Acts and Plans. In the next sections, we will present the most important policies and regulations for the Baltic and Mediterranean regional seas, primarily based on our desk analysis. A visual description of the various levels of governance is presented in Fig. 2.

Then we discuss the results from the stakeholder interviews to describe overarching drivers and barriers to marine litter policy and clean-up technology implementation in European seas.

4.1. Baltic Sea

4.1.1. EU and regional programmes in the Baltic

Regional cooperation is one of the main policy pillars in the Baltic Sea. In general, it can be observed that partners from countries around the Baltic Sea work together on transnational projects to address common challenges. Our analysis focused specifically on Estonia, Germany and Sweden, all members of the HELCOM Commission. Sweden and Germany are also members of the OSPAR Commission. Both the HELCOM and OSPAR Commissions have adopted Regional Action Plans for marine litter. There are also other regional collaborations, such as the

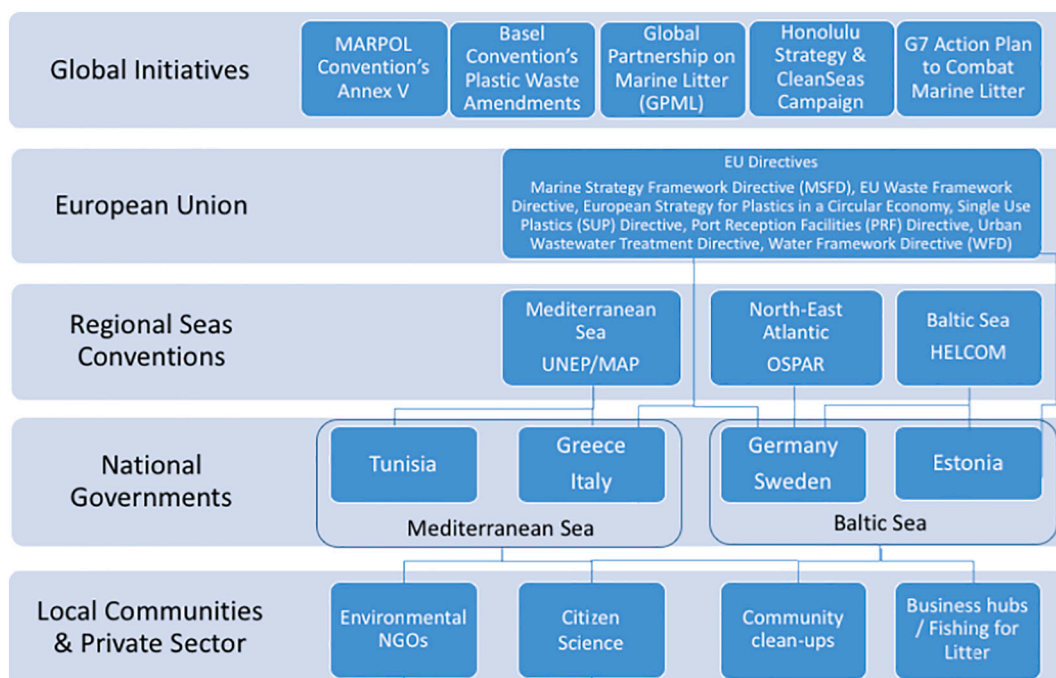


Fig. 2. Marine litter governance levels in the six selected countries of the Mediterranean and Baltic seas.

Nordic Council of Ministers, or the Gulf of Finland Road Map 2016–2020.

Funding sources for monitoring, research or coordinated actions in the Baltic region include state budgets, EU financial instruments, and funds from regional conventions. EU financial instruments include EU structural and investment funds such as the European Regional Development Fund, Cohesion Fund, and European Maritime and Fisheries Fund (EMFF), as well as targeted programmes such as the Horizon 2020 Research and Innovation programme and the LIFE programme for the environment and climate action. The Interreg Baltic Sea Region Programme 2014–2020 funded by the EU, supports integrated territorial development and cooperation for a more innovative, better accessible and sustainable Baltic Sea region. There are similar Interreg Programmes for other European seas, such as Interreg Atlantic Area, Interreg North Sea Region and Interreg Mediterranean. Some funds are also made available through HELCOM. State funding includes national Research Councils and more specifically the Environmental Investment Centre (KIK) in Estonia or the Swedish system in place for providing support to technical innovation and start-ups, such as the Swedish Agency for Economic and Regional Growth, the Swedish Innovation Agency (Vinnova), and the Swedish business developer Almi. All these bodies and organisations provide financial support for technical innovation and SMEs.

There is currently no systematic monitoring of microplastics, nor is a commonly agreed and harmonised monitoring method established. Monitoring currently only takes place in research projects and individual studies carried out by relevant authorities, county administrative boards or municipalities. However, research is ongoing nationally, as well as within HELCOM, OSPAR and the EU, to develop harmonised monitoring methods and appropriate indicators, and there is national, provincial, municipal, and sectoral (ports, industry) funding available for this.

4.1.2. National programmes in the Baltic

In addition, the three selected Baltic countries developed national programmes of measures stemming from the MSFD. Germany has initiated two action plans for marine litter through its G7 and G20 presidencies, in 2015 and 2017, respectively. Moreover, Germany committed to the implementation of a Ten-point Plan of Action for Marine Conservation and Sustainable Fisheries of the German Development Co-operation. Germany also established a National Round Table on Marine Litter in 2016 in order to facilitate the implementation of the MSFD which involves stakeholders from industry, academia, NGOs, as well as administration from municipalities, state and federal governments (Arroyo Schnell et al., 2017).

Sweden includes in its programme of measures a regulation on producer responsibility for packaging, a regulation on return systems for plastic bottles and metal cans, the Transport Agency's regulations on ship-source pollution measures that include plastic waste and has an act against pollution caused by ships (Arroyo Schnell et al., 2017). EurEau, an industry body representing water companies across Europe, highlights the results from a Swedish study where a WWTP in Malmö was able to remove up to 99% of microplastics from wastewater (EurEau, 2018). However, not all WWTPs seem to be equally effective. The Swedish Environmental Protection Agency (SEPA) funded a study in 2016 (Magnusson et al., 2016), which concludes that microplastic sources and pathways are still surrounded by many uncertainties, implying that it is unclear what the microplastics removal rate of existing WWTPs is.

Estonia includes measures regarding marine litter in its programme of measures for the MSFD, and made corresponding commitments during the UN Ocean Conference in New York 5–9 June 2017. Moreover, Estonia has a Packaging Act which covers all packaging placed on the market in the Republic of Estonia, and all packaging waste (including plastic) whether it is used or released at industrial, commercial, household, office or any other level. Finally, Estonia has a separate

Waste Act and beach-cleaning actions are also addressed in the Estonian Marine Strategy (Arroyo Schnell et al., 2017).

Focusing on specific national laws, many of the relevant pieces of legislation or policies that influence marine litter do not refer explicitly to marine litter as such, but are rather focused on waste management more generally. The treatment of waste that is considered 'municipal waste' is the responsibility of the municipalities, funded usually through municipal budgets and charges. Incineration of waste is strictly regulated and incineration of waste in territorial waters and Exclusive Economic Zones is banned. There are rules on emissions from wastewater treatment plants (WWTPs), although no specific requirements for the discharge of microplastics have been identified. Furthermore, there seems to exist disagreement on the extent to which WWTPs are effective in removing microplastics.

4.2. Mediterranean Sea

4.2.1. EU and regional programmes in the Mediterranean

All three Mediterranean countries in our study, Italy, Greece and Tunisia, are parties to UNEP/MAP, the Regional Sea Convention for the Mediterranean Sea. Therefore, although not mandatory or binding, the implementation of the Regional Plan on Marine Litter Management in the Mediterranean adopted by UNEP/MAP is an important instrument to collectively push towards the reduction of marine litter. For example, the EU funded project Marine Litter MED aims at supporting the UNEP/MAP Barcelona Convention and its Contracting Parties through the implementation of the Regional Plan on Marine Litter Management in the Mediterranean. UNEP cooperates with Tunisia's National Agency for the Protection of the Environment (ANPE) in the framework of the National Program for the Monitoring of Pollution. Also, using EU and own funds, UNEP/MAP, through one of its regional activity centres, supported the implementation of the Marine Litter Regional Plan in Tunisia. Other EU-funded projects include SwitchMed, the Interreg MED Programme and the Water and Environment Support (WES) in the European Neighbourhood Instrument (ENI) Southern Region in which Tunisia also participates.

Research on marine litter in Italy and Greece is mostly funded through European research programmes and funding from the respective Ministries of Environment, and sometimes through private donations. Marine litter collection is typically carried out through campaigns led and organised by environmental NGOs employing volunteers, also sometimes funded by private donors.

The management of wastewater follows the provisions of Directive 91/271/EEC concerning urban wastewater treatment as amended by Directive 98/15/EC. Although Italy has recently banned microplastics in cosmetic products (Law 205/2018), which will reduce the amount of microplastics in wastewater, there is no reference in the Italian or Greek legislation to enforce effluent concentration limits for plastics in WWTPs. European structural funds play an important role in the improvement of WWTPs in Southern Europe. For example, the European Regional Development Fund (ERDF) 2014–2020 allocated €655 million to urban WWTPs in Italy. European Investment Bank (EIB) loans are also used to upgrade and extend urban wastewater treatment, for example in Sardinia in 2018. The Joint European Support for Sustainable Investment in City Areas (JESSICA) initiative, developed by the European Commission and the European Investment Bank (EIB) in collaboration with the Council of Europe Development Bank (CEB), is another source of funding that can be used for litter management. JESSICA is not a new source of funding for member states, but rather a new way of using existing Structural Fund grant allocations to support specific urban development projects, like upgrading WWTPs. The costs of marine litter monitoring are also covered by EU Structural Funds in Italy and Greece, and by funds from the respective Ministries of the Environment. Emphasis is placed on the protection and conservation of high-quality bathing waters with the annual implementation of bathing water monitoring programmes. Italy is carrying out some monitoring activities

which cover microplastics on the sea surface and waste on beaches.

4.2.2. National programmes in the Mediterranean

Around the Mediterranean Sea, the EU members Greece and Italy have national programmes of measures stemming from the MSFD. Because Tunisia is not an EU member state, the funding of its national programme comes from various sources. In Greece, the National Marine Strategy includes concrete descriptors for ensuring a Good Environmental Status including one on marine litter. Additionally, there is the Waste Management Plan and the accompanying National Strategic Plan for Waste Prevention as well as national legislation on Waste and Recycling. Particular emphasis is placed in Greece on the protection and conservation of high-quality beaches and bathing waters. For this purpose, there are extended monitoring programmes in Greece by academic research organisations and clean-up campaigns by NGOs (Arroyo Schnell et al., 2017).

Italy is part of a plastic bag coalition initiated by France, Monaco and Morocco in 2016, which aims at promoting the reduction of plastic waste pollution of the oceans and in particular the elimination of single-use plastic bags in all countries. Additionally, Italy ensures compliance with requirements related to environmental impact assessments in coastal and marine areas and to minimizing marine pollution with the law Provisions on the Environment to Promote the Green Economy and to Restrict the Excessive Use of Natural Resources. Italy has already banned the distribution of lightweight plastic bags that are not from biodegradable sources and has existing measures addressing the regulation of single-use bags (Arroyo Schnell et al., 2017).

In Tunisia, after the Jasmine revolution early 2011, waste management largely collapsed in both urban and rural areas due to the disruption of most waste collection, infrastructure and recycling channels. Currently, Tunisia produces more than 2.8 million tons of solid waste, of which 9.4% is plastics. Almost 95% of this waste amount ends up in landfills which leak toxic chemicals into the ground and water supply according to the National Waste Management Agency ANGeD (Agence Nationale de Gestion des Déchets) (Bünemann et al., 2020). The eight operating landfills are reaching the end of their life and call for swift alternative solutions such as waste recovery. One promising initiative is Eco-lef, created in 2001 and managed by ANGeD that facilitates the recovery of used packaging. Eco-lef is the first packaging management system in the Middle East and North Africa region (Bünemann et al., 2020). Overall, however, inadequate funding for WWTPs is a major obstacle for the effective management of marine litter and other waste streams in Tunisia (Arroyo Schnell et al., 2017).

4.3. Stakeholder perceptions of drivers of policy implementation

The stakeholders' interviews revealed their opinions on the most important drivers of policy implementation concerning marine litter. Whereas the previous sections were based on the desk-study of six specific countries in the Mediterranean and the Baltic seas, the interviews were conducted with regional and national experts from all over Europe, hence the results concern all European seas with no distinction. As an open-ended interview protocol was used, the drivers and barriers were identified and brought up by the stakeholders themselves. We present the drivers here according to their importance by counting the number of times interviewees mentioned and discussed them, as presented in Table 1.

4.3.1. Role of civil society

The stakeholder interviews served to gauge real-world experiences with and perceptions of marine litter clean-up policies, and to identify drivers and barriers to the implementation and diffusion of marine litter technologies. Based on these interviews, the role of civil society was identified as crucial in helping to implement environmental policy. A relevant example is the Fishing for Litter project, a voluntary initiative where fishermen collect litter into bags on board while fishing, take it to

Table 1

Drivers and barriers of policy implementation concerning marine litter and relative importance, as identified by key stakeholders and experts.

Main drivers	Main barriers
Research (9)	Financial challenges/responsibility (10)
Role of civil society (8)	Environmental policy/legislation (10)
Strong legislative and policy framework (8)	Limited knowledge on technological feasibility (8)
Incentives/positive publicity (7)	Consumer behaviour (2)
Ecolabels (6)	High administrative (transaction) costs (2)
Private sector/industry (4)	
Consumer behaviour (4)	
Citizen science/monitoring (4)	
High synergistic potential (2)	

Note: in order to proxy the relative importance of each driver or barrier, the number of stakeholders or experts referring to a specific driver or barrier is presented between brackets.

shore at no cost, and deliver it to the local authorities. Small financial support is given to provide the bags and collection facilities. The Fishing for Litter project has become an integral part of the Port Reception Facilities Directive.

4.3.2. Strong legislative and policy framework and consumer behaviour

Bottom-up public initiatives are not considered sufficient to address marine litter problems without a top-down national policy framework to regulate this common resource problem. Emphasis was placed on the importance of pressure from national governments to bring about change in the management of marine litter and the need for a stronger legislative framework, which should be as specific in its provisions as possible. In order to reduce marine litter, measures first need to be taken by the government, for example to increase recycling, instead of shifting the responsibility entirely onto citizens. The role of consumer behaviour is very important, but responsibility for solving the problem should be shared and not be borne by one group only according to the interviewed stakeholders. An adequate and effective legislative framework is important in all aspects of litter management, including monitoring. Additionally, complementary legal instruments are required for litter originating from rivers, better connecting the MSFD which focuses on marine areas to the WFD which focuses mainly on freshwaters like rivers on land. This illustrates that regulatory, legislative frameworks such as the MSFD and WFD can play a role as one of the primary drivers of the implementation of marine litter clean-up technologies.

4.3.3. Incentives

Another main driver of action is the existence of incentives, both monetary, such as access to investment funds, and non-monetary, such as positive publicity. A solid financial basis would support the introduction of innovative technologies for wastewater treatment plants on land, because it is challenging to incentivize the industry to change sector practices. Support to new SMEs and start-up companies could further help in that respect, because these may be more innovative than incumbent companies and service providers. Influential early adopters of technologies, for example through pilot projects, can trigger uptake and wider diffusion of these technologies in industry by demonstrating the effectiveness and benefits. Ecolabels can be an incentive to stimulate demand and raise awareness, but they were only considered useful if the labels were clear and targeted, and accompanied by transparent guidelines and accountability measures.

4.3.4. Research and citizen science

Research is also considered a crucial driver for marine litter policy implementation. Setting benchmarks and baseline values through appropriate and sound scientific research is the only way to assess the effectiveness of a given strategy. Emphasis was placed on the importance of collaboration between researchers, such as through international

research projects. Environmental NGOs also play an essential role in many EU countries in marine litter monitoring campaigns in collaboration with research institutes. Citizen-science interactions, NGO led beach clean-ups and awareness campaigns were brought up as a way to engage communities in knowledge creation and monitoring.

4.3.5. Creating synergies

Finally, as is true for all efforts to change and implement environmental policy, the formation of synergies is critical. Synergistic effects can emerge from all types of cross-sectoral and cross-stakeholder collaborations, aligning supply chains of products and commodities, public-private partnerships, and creating synergies through inter-academic collaboration and partnerships of SMEs with scientific institutions. The important role of the private sector was mentioned since companies can form key innovative partnerships and business hubs which can in turn pool expertise and resources. Larger companies can also invest in new technologies or shift to a more sustainable business model, but these practices should be regulated to guarantee the desired outcome of reducing marine litter.

4.4. Stakeholder perceptions of barriers to policy implementation

Stakeholders were also asked about possible barriers to policy implementation concerning marine litter during the interview. As for the identified drivers in the previous section, the main barriers to policy implementation identified by the stakeholders themselves are presented below according to their importance as presented in [Table 1](#).

4.4.1. Financial challenges

Among the main barriers to marine litter policy implementation is the high cost involved and the difficulty of financing litter collection and management, including cost recovery of litter management. The financial viability of litter transformation initiatives and recycling can be challenging due to the nature of marine litter as highly variable and weathered. From a sustainable business model point of view, it is difficult to develop a concrete business case because it can be hard to determine who is the paying customer when it comes to marine litter and microplastics.

4.4.2. Responsibility of actors

Concerns were also expressed about determining who is responsible, among the various actors associated with marine pollution, for paying for the development and implementation of marine litter clean-up technologies. From a public or industry point of view, there are limited regulations to assign responsibility paired with a low level of awareness of the problem itself, but also of how each stakeholder contributes to the problem. A lack of a sense of urgency was also mentioned as an obstacle to the implementation of marine litter policy, and a reason that littering continues from various sources.

4.4.3. Inadequacy of the existing regulatory framework

The existing regulatory framework can be a barrier if it is either absent or not properly implemented. For instance, there are hardly any policies that define limits for the amounts of microplastics allowed in fresh and marine waters. The lack of implementation of existing marine litter policy is in some cases attributed to issues of water rights and water use permits, as well as jurisdictional divisions between private and public (local, regional, provincial, or national) responsibilities over water management. It was also recommended to revisit existing marine and freshwater policies in view of the fact that plastics are not the only problem in wastewater treatment and discharge. For example, there are issues of pharmaceuticals, nutrients, heavy metals and endocrine disruptors and other micro-pollutants that should be tackled simultaneously.

4.4.4. Limited knowledge on technological feasibility

Another barrier may be the lack of (sufficient) evidence that new technologies for marine litter management are cost-effective, sustainable, and more environmentally beneficial compared to existing technologies. Not only technologies but also practical experiences, such as lessons learned and challenges, need to be shared between countries in order to achieve the necessary up-scaling and possible economies of scale. A crucial issue in developing these new technologies is the research defining parameters such as impact on litter reduction, potential negative environmental effects and variables such as cost-effectiveness. There is currently very limited data and information available about existing technologies that are already on the market or in the process of being marketed. The absence of such data brings up another obstacle, namely financing the research needed to test and prove these technologies and define their impacts.

4.4.5. Consumer behaviour

A relatively underestimated or disregarded factor is consumer behaviour. Focusing on the role of stakeholders, we tend to ignore the role of consumers. Misbehaviour and littering can pose a serious problem, even if the necessary waste disposal infrastructure and improved products exist, and harmonised or less polymer containing products are allowed. Notable examples are countries like Singapore where strict laws on littering apply, or Japan where there are no waste bins in public transportation systems because people are expected to dispose of their own waste in the appropriate way. Behavioural change is needed so that consumers' actions are not guided by indifference or lack of awareness.

4.4.6. High administrative costs

Finally, as is the case for most environmental policy, administrative issues resulting in high transaction costs are often a major barrier to implementation. Marine litter seems to be such a case, especially because it is a unique material which poses particular challenges. The processing of marine litter requires permits and regulations, which in turn can increase taxes and tariffs on the products and commodities in which it is used (e.g. recycled material), and this can lead to delays. Third party certification is critical, but expected to increase the administrative burden.

5. Conclusions

This article identified (1) the relevant regulatory and policy frameworks, including financing instruments, related to marine litter in six selected countries, three surrounding the Baltic Sea and three surrounding the Mediterranean Sea, and (2) the main drivers and barriers to the adoption and diffusion of marine litter clean-up technologies that can be used to meet a Good Environmental Status in European seas. The comprehensive review was based on a combination of available policy data and documentation and country-specific expert knowledge and understanding. Despite the extensive review, there is always a possibility that we may have overlooked a specific law or regulation in a country. Moreover, we emphasise that the stakeholder views summarized in this study do not include those of the plastics industry.

Looking at the legislative framework, with the exception of Tunisia, the management of marine waste is mainly regulated through EU-level, rather than national, legislation. The Regional Action Plans in both seas provide important guidance and especially in the Baltic Sea are a crucial means of funding. In addition, it is important to point out that global policy instruments are available which are relevant to all countries bordering the Baltic and Mediterranean Seas. These policy instruments include the action plan on plastic litter from ships adopted by the International Maritime Organization (IMO) in 2018, and the resolution adopted by the 4th UN Environment Assembly (UNEA) in 2019, aiming to tackle ocean pollution from plastics, in particular microplastics and single use plastic products. It is also worth noting that the IMO, through MARPOL, had already prohibited the disposal of garbage including

plastics almost 30 years ago.

All countries included in our study seem to benefit from EU funding through specific programmes and projects and in some cases through the Regional Sea Conventions. State funding is also available, especially in the Baltic Sea countries. In the case of Tunisia, apart from various EU funded projects in cooperation with EU member states, a large part of the necessary funding comes from foreign aid and investments, although there is some state support for technical innovation and start-up companies.

A strong regulatory framework, accompanied by national and multilateral institutions to implement and administer this framework and its associated rules and regulations, is an indispensable precondition for a cost-effective and sustainable management of marine litter in the Baltic and Mediterranean seas. Managing marine litter in transboundary marine waters, originating from a wide variety of point and non-point sources, is a tremendous challenge and requires coordinated multilateral action. A critical observation here is that the legal and policy framework addressing marine litter in European seas does not seem to conform with the so called 'polluter pays principle', but is rather based on post-pollution remedies, mainly consisting of clean-up of marine litter by public agencies like municipalities and the state. Responsibilities and hence accountability need to be better defined in order to be able to design and apply more sustainable cost-sharing mechanisms and agreements for expensive clean-up efforts and tools.

Moreover, it seems that authorities responsible for marine litter have concluded that additional treatment technologies to address emissions of microplastics are not necessarily a priority, and cleaning up litter is perceived as less costly than preventing it from entering into the European seas. More evidence is needed to demonstrate the benefits of preventive action compared to post-pollution clean-up, also in terms of avoided damage to ecosystem health and ultimately human welfare and well-being. Such evidence could be given through the development of more sustainable business cases, which require a new regulatory framework that fosters new ideas and technologies to reduce plastic pollution and the adoption and diffusion of best management practices across EU member states. New technologies have to prove that they are more sustainable and both financially and environmentally beneficial, otherwise it will be challenging to attract interest and create market demand. Knowledge sharing between member states and other countries bordering European seas is paramount to achieve the necessary adoption, diffusion and upscaling of new marine litter technologies.

CRediT authorship contribution statement

Sofia Frantzi: Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Roy Brouwer:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Emma Watkins:** Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing. **Pieter van Beukering:** Writing – review & editing. **Maria Conceição Cunha:** Investigation, Writing – review & editing. **Hanna Dijkstra:** Investigation, Writing – review & editing. **Sem Duijndam:** Investigation, Writing – review & editing. **Hela Jaziri:** Investigation, Writing – review & editing. **Ikechukwu Charles Okoli:** Investigation. **Mia Pantzar:** Investigation. **Ignacio Rada Cotera:** Investigation, Writing – review & editing. **Katrin Rehdanz:** Investigation, Writing – review & editing. **Karsten Seidel:** Investigation, Writing – review & editing. **George Triantaphyllidis:** Investigation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability statement

Due to the sensitive nature of the questions asked in this study during the stakeholder interviews, respondents were assured raw data would remain confidential and would not be shared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpolbul.2021.112611>.

References

- Arroyo Schnell, A., Klein, N., Gómez Girón, E., Sousa, J., 2017. National Marine Plastic Litter Policies in EU Member States: An Overview. Brussels, Belgium. <https://portals.iucn.org/library/sites/library/files/documents/2017-052.pdf>.
- Barboza, L.G.A., Vethaak, A.D., Lavorante, B.R.B.O., Lundebye, A.-K., Guilhermino, L., 2018. Marine microplastic debris: an emerging issue for food security, food safety and human health. *Mar. Pollut. Bull.* 133, 336–348. <https://doi.org/10.1016/j.marpolbul.2018.05.047>.
- Beaumont, N.J., Aanesen, M., Austen, M.C., Börger, T., Clark, J.R., Cole, M., Hooper, T., Lindeque, P.K., Pascoe, C., Wyles, K.J., 2019. Global ecological, social and economic impacts of marine plastic. *Mar. Pollut. Bull.* 142, 189–195. <https://doi.org/10.1016/j.marpolbul.2019.03.022>.
- Bergmann, M., Gutow, L., Clages, M. (Eds.), 2015. *Marine Anthropogenic Litter*. Springer International Publishing, Cham.
- Borrelle, S.B., Rochman, C.M., Liboiron, M., Bond, A.L., Lusher, A., Bradshaw, H., Provencher, J.F., 2017. Opinion: why we need an international agreement on marine plastic pollution. *Proc. Natl. Acad. Sci.* 114, 9994–9997. <https://doi.org/10.1073/pnas.1714450114>.
- Brouwer, R., Hadzhiyska, D., Ioakeimidis, C., Ouderdorp, H., 2017. The social costs of marine litter along European coasts. *Ocean Coast. Manag.* 138, 38–49. <https://doi.org/10.1016/j.ocecoaman.2017.01.011>.
- Bünemann, A., Brinkmann, J., Löhle, S., Bartnik, S., 2020. ECO-LEF in Tunisia: a case study. In: *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. PREVENT Waste Alliance, Bonn, Germany*.
- Chen, C.-L., 2015. Regulation and management of marine litter, in: Bergmann Melanie and Gutow, L. and K.M. (Ed.), *Marine Anthropogenic Litter*. Springer International Publishing, Cham, pp. 395–428. doi:https://doi.org/10.1007/978-3-319-16510-3_15.
- Dauvergne, P., 2018. Why is the global governance of plastic failing the oceans? *Glob. Environ. Chang.* 51, 22–31. <https://doi.org/10.1016/j.gloenvcha.2018.05.002>.
- Dijkstra, H., van Beukering, P., Brouwer, R., 2020. Business models and sustainable plastic management: a systematic review of the literature. *J. Clean. Prod.* 258, 120967. <https://doi.org/10.1016/j.jclepro.2020.120967>.
- Dijkstra, H., van Beukering, P., Brouwer, R., 2021. In the business of dirty oceans: overview of startups and entrepreneurs managing marine plastic. *Mar. Pollut. Bull.* 162, 111880. <https://doi.org/10.1016/j.marpolbul.2020.111880>.
- EurEau, 2018. Swedish Report on WWTP and Microplastics.
- Gago, J., Booth, A.M., Tiller, R., Maes, T., Larreta, J., 2020. Microplastics pollution and regulation, in: Rocha-Santos Teresa and Costa, M. and M.C. (Ed.), *Handbook of Microplastics in the Environment*. Springer International Publishing, Cham, pp. 1–27. doi:https://doi.org/10.1007/978-3-030-10618-8_52-1.
- Galgani, F., Hanke, G., Werner, S., de Vrees, L., 2013. Marine litter within the European marine strategy framework directive. *ICES J. Mar. Sci.* <https://doi.org/10.1093/icesjms/fst122>.
- Haward, M., 2018. Plastic pollution of the world's seas and oceans as a contemporary challenge in ocean governance. *Nat. Commun.* 9, 667. <https://doi.org/10.1038/s41467-018-03104-3>.
- Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. *Science* 347, 768–771. <https://doi.org/10.1126/science.1260352>.
- Law, K.L., 2017. Plastics in the marine environment. *Annu. Rev. Mar. Sci.* 9, 205–229. <https://doi.org/10.1146/annurev-marine-010816-060409>.

- Law, K.L., Thompson, R.C., 2014. Microplastics in the seas. *Science* 345, 144–145. <https://doi.org/10.1126/science.1254065>.
- Leslie, H.A., Depledge, M.H., 2020. Where is the evidence that human exposure to microplastics is safe? *Environ. Int.* 142, 105807. <https://doi.org/10.1016/j.envint.2020.105807>.
- Löhr, A., Savelli, H., Beunen, R., Kalz, M., Ragas, A., van Belleghem, F., 2017. Solutions for global marine litter pollution. *Curr. Opin. Environ. Sustain.* 28, 90–99. <https://doi.org/10.1016/j.cosust.2017.08.009>.
- Maes, T., Perry, J., Alliji, K., Clarke, C., Birchenough, S.N.R., 2019. Shades of grey: marine litter research developments in Europe. *Mar. Pollut. Bull.* 146, 274–281. <https://doi.org/10.1016/j.marpolbul.2019.06.019>.
- Magnusson, K., Eliasson, K., Fråne, A., Haikonen, K., Hultén, J., Olshammar, M., Stadmark, J., Voisin, A., 2016. Swedish Sources and Pathways for Microplastics to the Marine Environment a Review of Existing Data. Report Number C183. Stockholm.
- Molina Jack, M.E., del Mar Chaves Montero, M., Galgani, F., Giorgetti, A., Vinci, M., le Moigne, M., Brosich, A., 2019. EMODnet marine litter data management at pan-European scale. *Ocean Coast. Manag.* 181, 104930 <https://doi.org/10.1016/j.ocecoaman.2019.104930>.
- Mouat, J., Lozano, R.L., Bateson, H., 2010. Economic Impacts of Marine Litter. KIMO International, 105p. <http://www.kimointernational.org/wp/wp-content/uploads/2017/09/KIMO-Economic-Impacts-of-Marine-Litter.pdf>.
- Oosterhuis, F., Papyrakis, E., Boteler, B., 2014. Economic instruments and marine litter control. *Ocean Coast. Manag.* 102, 47–54. <https://doi.org/10.1016/j.ocecoaman.2014.08.005>.
- Rochman, C.M., Browne, M.A., Halpern, B.S., Hentschel, B.T., Hoh, E., Karapanagioti, H. K., Rios-Mendoza, L.M., Takada, H., Teh, S., Thompson, R.C., 2013. Classify plastic waste as hazardous. *Nature* 494, 169–171. <https://doi.org/10.1038/494169a>.
- Ryan, P.G., 2015. A brief history of marine litter research, in: Bergmann Melanie and Gutow, L. and K.M. (Ed.), *Marine Anthropogenic Litter*. Springer International Publishing, Cham, pp. 1–25. doi:https://doi.org/10.1007/978-3-319-16510-3_1.
- Stoll, T., Stoett, P., Vince, J., Hardesty, B.D., 2020. Governance and measures for the prevention of marine debris, in: Rocha-Santos Teresa and Costa, M. and M.C. (Ed.), *Handbook of Microplastics in the Environment*. Springer International Publishing, Cham, pp. 1–23. doi:https://doi.org/10.1007/978-3-030-10618-8_26-1.
- ten Brink, P., Schweitzer, J.-P., Watkins, E., Janssens, C., Smet, M. de, Leslie, H., Galgani, F., 2018. Circular Economy Measures to Keep Plastics and Their Value in the Economy, Avoid Waste and Reduce Marine Litter. Kiel Institute for the World Economy (IfW), Kiel.
- Tiller, R., Nyman, E., 2018. Ocean plastics and the BBNJ treaty—is plastic frightening enough to insert itself into the BBNJ treaty, or do we need to wait for a treaty of its own? *J. Environ. Stud. Sci.* 8, 411–415. <https://doi.org/10.1007/s13412-018-0495-4>.
- UNEP, 2016a. Marine Plastic Debris and Microplastics – Global Lessons and Research to Inspire Action and Guide Policy Change. Nairobi, Kenya. <https://wedocs.unep.org/handle/20.500.11822/7720>.
- UNEP, 2016b. Marine Litter Legislation: A Toolkit for Policymakers. Nairobi, Kenya. <https://www.unep.org/resources/report/marine-litter-legislation-toolkit-policymakers>.
- Vethaak, A.D., Leslie, H.A., 2016. Plastic debris is a human health issue. *Environ. Sci. Technol.* 50, 6825–6826. <https://doi.org/10.1021/acs.est.6b02569>.
- Vince, J., Hardesty, B.D., 2017. Plastic pollution challenges in marine and coastal environments: from local to global governance. *Restor. Ecol.* 25, 123–128. <https://doi.org/10.1111/rec.12388>.
- Vince, J., Hardesty, B.D., 2018. Governance solutions to the tragedy of the commons that marine plastics have become. *Front. Mar. Sci.* 5, 214. <https://doi.org/10.3389/fmars.2018.00214>.
- Xanthos, D., Walker, T.R., 2017. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): a review. *Mar. Pollut. Bull.* <https://doi.org/10.1016/j.marpolbul.2017.02.048>.