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A multi-criteria assessment of policies to achieve the objectives of the EU marine litter strategy

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ABSTRACT

This paper proposes and assesses policy options to achieve the objectives of the EU marine litter strategy, based on the existing EU legislation. A group of experts and stakeholders was involved through a multi-staged workshop organized to generate the information to assess the contribution of the policies to the set of objectives, as well as the relative importance of the objectives, on qualitative scales. The ELECTRE TRI multi-criteria decision analysis method was used to rate the policies, which were subsequently ranked. Per the results, all policies deserve to be considered, even when the more pessimistic assessments (33rd percentile) are used. Revising the Urban Wastewater Treatment Directive, setting legislative targets on marine litter and ensure they are fully monitored, and funding proven clean-up technologies were deemed to be the most potentially impactful policies. The remaining policies assessed can nevertheless play an important role in complementing the higher-ranked policies.

1. Introduction

Marine litter is a severe global problem, with plastic debris contributing the largest amount of pollution (Chrissley et al., 2017, Parga Martínez et al., 2020, Plastics Europe, 2020). A significant plastic pollution increase is likely unless reduction actions are implemented (plastics could double by 2050, as mentioned in Hohn et al., 2020).

Terrestrial and marine ecosystems and the associated ecosystem services are being radically harmed (Beaumont et al., 2019), along with a wide variety of activities that include aquaculture, fisheries, marine transportation, tourism, etc. The effects of plastic debris have become a major impediment to sustainable development and therefore there is considerable pressure to intervene to prevent, clean up and mitigate the effects of litter. Taking measures to prevent additional negative impacts on the environment and economy has turned out to be an increasingly critical priority and a key political issue.

However, these are complex problems in an area peopled by a variety of actors with conflicting perspectives that include marine-based industry in general, environmentalists, consumers, financial institutions, policy makers, governments, etc. While many initiatives have been proposed to deal with the aforementioned problems, they have been hampered by a lack of robust legal and policy frameworks as well as other instruments, along with mechanisms to implement solutions that do in fact exist (Frantzi et al., 2021). Furthermore, all too often no link can be found to support the implementation of specific actions as emphasized in van Oosterhout et al. (2021) and Watkins et al., 2021 for the adoption of marine clean-up technologies.

Nowadays, there is a vast group of areas in the spotlight asking for the development of public policies, such as climate change, energy generation, sustainable water protection and allocation. Plastics have added a new challenge to public policy design, to explicitly make sound recommendations for real-world informed decisions.

Public policy issues must be structured in the scope of strategic decision making. Public policy decisions to define the best course of action are complex because of the underlying public interests (Keeney, 2004). This means evaluating policy options against objectives encompassing all consequences that represent public concerns (economic, social and environmental impacts). The success of a decision-making process depends on the ability to simultaneously embrace different points of view, covering all the issues that need attention, and on accounting for the preferences set by stakeholders (as acceptable trade-offs for performance among objectives (Talantsev et al., 2016)).

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The above motivations, concerning the severe problem of marine litter and the need to develop policies to address it, have led to the development of the European project CLAIM (Cleaning Litter by developing and Applying Innovative Methods in European seas), funded by the European Union under grant agreement No 774586. As part of this project's activities, legal, institutional and financial drivers and barriers have been identified (see, in this journal, Frantzi et al., 2021) and two policy briefs have been developed (van Oosterhout et al., 2021; Watkins et al., 2021). The present paper elaborates on this previous work and addresses the problem of assessing and prioritizing a set of policies, involving experts and stakeholders in the process, aiming to establish recommendations for the EU on the most promising policies that can contribute to realize the objectives of its marine litter strategy.

The methodological framework to perform the assessment of the proposed policies is Multiple Criteria Decision Analysis (MCDA), which addresses decision-making problems when multiple evaluation dimensions are involved, as is naturally the case here. MCDA is covered in several books as a multipurpose framework (e.g., Belton and Stewart, 2002; Greco et al., 2016; Ishizaka and Nemery, 2013), and several authors have reviewed and argued for the adequateness of MCDA to cope with environmental, and, more generally, sustainability challenges (Cinelli et al., 2014; Ibáñez-Forés et al., 2014; Diaz-Balteiro et al., 2017; Stojčić et al., 2019; Lindfors, 2021). More particularly, Santos et al. (2022) present a systematic review of MCDA applications addressing marine and terrestrial plastic waste management. Moreover, MCDA is particularly suited to support the participation of experts and stakeholders (Marttunen et al., 2015), which was also a requisite in this research.

MCDA is also recognized as a useful tool that can offer a clear, well-organized way and an in-depth evaluation framework to provide informed public policy decisions. Indeed, the literature shows different applications of MCDA in a range of areas where public policies are evaluated or proposed: Doukas (2013) to analyze policy options to support the restructuring of the energy sector; Woods et al., 2016 for developing government policies and public health interventions for modifiable population exposure to environmental health hazards; Blanco et al., 2017 for evaluating policy options for hydropower surplus utilization in Paraguay in the context of an energy transition process; Garmendia et al., 2017 for building an Adaptive Marine Policy toolbox as a useful and operational framework to manage "the intrinsically dynamic and complex marine ecosystems", which has been applied to the marine litter issue in the Mediterranean and Black Sea as an example; Chalabi et al., 2017 for assessing UK air quality policies; Dias et al., 2018 for creating a methodology to assess policies to foster technological innovations in the electricity sector that has been applied to the case study of smart grids in Brazil; Carvalho et al., 2019 to define regulatory policy options to improve wastewater coverage in Brazil, and Cohen et al. (2019) to analyze climate mitigation and development policies in Chile, Colombia, and India. The above are just some recent examples closer to the topic of the present work.

As far as the recent search of the literature by Santos et al. (2022) is concerned, no MCDA study has ever been developed to support public policy processes for tackling marine litter and so this paper aims to provide more sustainable avenues for all the activities based on European seas.

The previous overview established the need for assessing policies to achieve the objectives of the EU marine litter strategy, the need to involve experts and stakeholders in this assessment, the proven adequacy of MCDA methods for this endeavour, and the lack of previous MCDA policy assessments in the marine litter context. This paper therefore contributes to the literature by proposing and assessing policy options using a version of the ELECTRE TRI MCDA method (justifications and more details are provided in Section 2) to deal with qualitative statements obtained in the course of a workshop with an international panel of relevant experts and stakeholders for the topic of marine litter.

This paper is organized in four sections. After this introduction, the main components of the MCDA framework are presented and discussed. The information needed and methods used to perform the assessment of policy options against EU marine strategy objectives are also provided, as well as methods for rating and ranking. The third section shows the results of a real-world application in terms of policy prioritization based on an elicitation process involving experts and stakeholders. The fourth and last section presents the conclusions of the study, emphasizing some recommendations.

2. Materials and methods

The MCDA framework to be developed comprises five components:

- Policy options (Pi: P - Policy; i - its number) – options to be assessed to inform the EU on the most favourable policies to fulfil the EU Marine Strategy Framework Directive (MSFD, 2008/56/EC);
- Objectives for the assessment (Oj: O - Objective; j - its number) – objectives of the EU MSFD against which the policies will be assessed;
- Elicitation process – perspectives are collected from multiple experts and stakeholders for the assessment of the policies (a spreadsheet template, shown in Fig. 1, was provided for this purpose, for experts and stakeholders to perform the elicitation process; a detailed explanation is given in the next sections);
- Rating process – each policy is rated using the ELECTRE TRI method (Figueira et al., 2013), given the impacts of the policy on multiple objectives already assessed;
- Ranking process – policies are ranked in terms of relative priority.

2.1. Policy options

There are a number of existing policies and laws relevant to tackling macroplastic and microplastic marine litter. With regard to plastic debris, it is important to make a distinction between microplastics (< 5 mm) and macroplastics (> 5 mm) because their impacts should be managed through policies and actions with different characteristics.

Worldwide international measures include: the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex V[1] which bans ships from dumping litter at sea; Amendments to Annexes II, VIII and IX to the Basel Convention (2019)[2]; the Global Partnership on Marine Litter (GPML)[3]; UNEP's Honolulu strategy (UNEP and NOAA, 2011) and CleanSeas campaign[4]; and the G7 (2015) and G20 (2017) Action Plans on marine litter. There is also significant regional level cooperation, for example the HELCOM (HELCOM, 2021) and OSPAR Regional Action Plans on Marine Litter (OSPAR, 2014) and the Regional Plan on Marine Litter Management in the Mediterranean (MLRP, 2013). At the EU level, the EU Marine Strategy Framework Directive (MSFD) (2008/56/EC) includes marine litter as a descriptor (No. 10) to be monitored, and the EU Port Reception Facilities (PRF) Directive (2019/883/EU) aims to reduce the discharge of ship-generated waste and cargo residues at sea. On plastics specifically, the EU's 2018 Strategy for Plastics in a Circular Economy (COM/2018/028 final)[5] formed part of

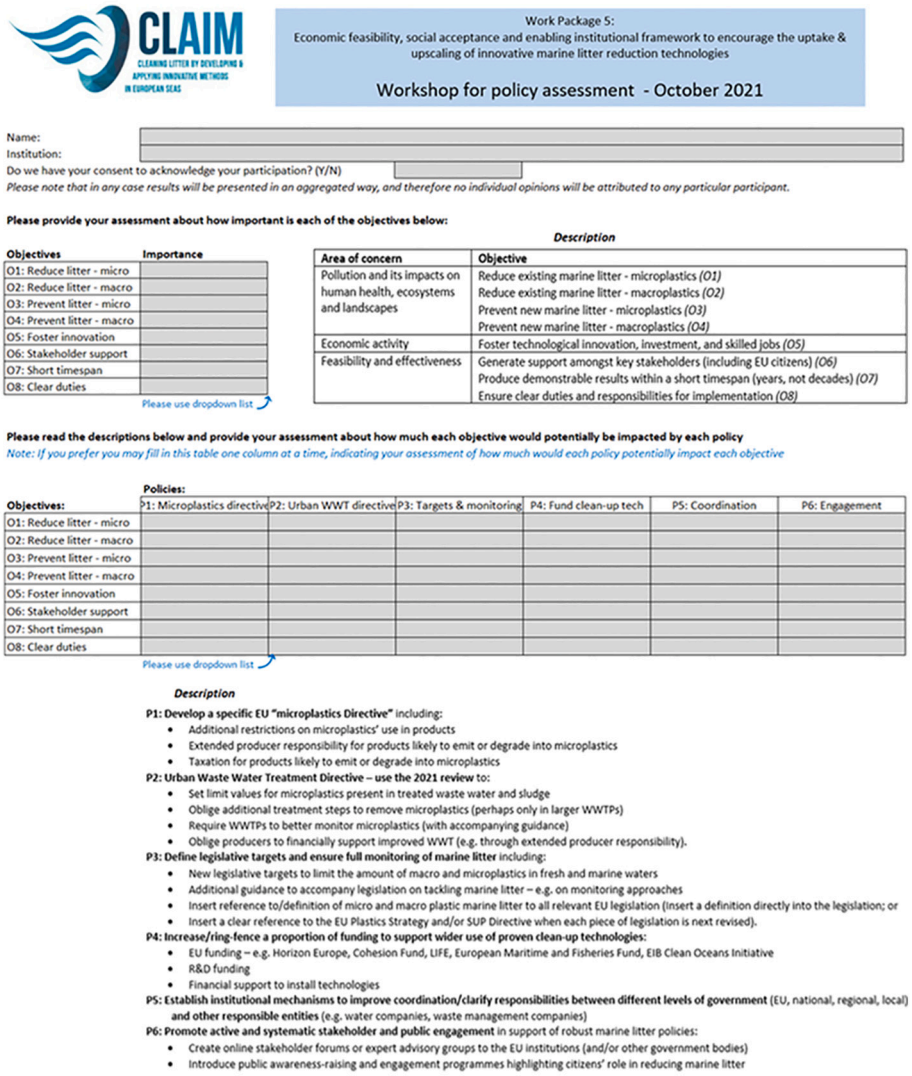
[1] https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Simplified%20overview%20of%20the%20discharge%20provisions%20of%20the%20revised%20MARPOL%20Annex%20V.pdf

[2] http://www.basel.int/Implementation/Plasticwaste/Decisions/tabid/6069/Default.aspx

[3] http://www.gpmarinelitter.org

[4] http://www.cleanseas.org

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A28%3AFIN



Work Package 5:
Economic feasibility, social acceptance and enabling institutional framework to encourage the uptake & upscaling of innovative marine litter reduction technologies

Workshop for policy assessment - October 2021

Name:
Institution:
Do we have your consent to acknowledge your participation? (Y/N)
Please note that in any case results will be presented in an aggregated way, and therefore no individual opinions will be attributed to any particular participant.

Please provide your assessment about how important is each of the objectives below:

Objectives	Importance
O1: Reduce litter - micro	
O2: Reduce litter - macro	
O3: Prevent litter - micro	
O4: Prevent litter - macro	
O5: Foster innovation	
O6: Stakeholder support	
O7: Short timespan	
O8: Clear duties	

Please use dropdown list

Description

Area of concern	Objective
Pollution and its impacts on human health, ecosystems and landscapes	Reduce existing marine litter - microplastics *(O1)* Reduce existing marine litter - macroplastics *(O2)* Prevent new marine litter - microplastics *(O3)* Prevent new marine litter - macroplastics *(O4)*
Economic activity	Foster technological innovation, investment, and skilled jobs *(O5)*
Feasibility and effectiveness	Generate support amongst key stakeholders (including EU citizens) *(O6)* Produce demonstrable results within a short timespan (years, not decades) *(O7)* Ensure clear duties and responsibilities for implementation *(O8)*

Please read the descriptions below and provide your assessment about how much each objective would potentially be impacted by each policy
Note: If you prefer you may fill in this table one column at a time, indicating your assessment of how much would each policy potentially impact each objective

Objectives: / Policies:	P1: Microplastics directive	P2: Urban WWT directive	P3: Targets & monitoring	P4: Fund clean-up tech	P5: Coordination	P6: Engagement
O1: Reduce litter - micro						
O2: Reduce litter - macro						
O3: Prevent litter - micro						
O4: Prevent litter - macro						
O5: Foster innovation						
O6: Stakeholder support						
O7: Short timespan						
O8: Clear duties						

Please use dropdown list

Description

P1: Develop a specific EU "microplastics Directive" including:
- Additional restrictions on microplastics' use in products
- Extended producer responsibility for products likely to emit or degrade into microplastics
- Taxation for products likely to emit or degrade into microplastics

P2: Urban Waste Water Treatment Directive – use the 2021 review to:
- Set limit values for microplastics present in treated waste water and sludge
- Oblige additional treatment steps to remove microplastics (perhaps only in larger WWTPs)
- Require WWTPs to better monitor microplastics (with accompanying guidance)
- Oblige producers to financially support improved WWT (e.g. through extended producer responsibility).

P3: Define legislative targets and ensure full monitoring of marine litter including:
- New legislative targets to limit the amount of macro and microplastics in fresh and marine waters
- Additional guidance to accompany legislation on tackling marine litter – e.g. on monitoring approaches
- Insert reference to/definition of micro and macro plastic marine litter to all relevant EU legislation (insert a definition directly into the legislation; or
- Insert a clear reference to the EU Plastics Strategy and/or SUP Directive when each piece of legislation is next revised).

P4: Increase/ring-fence a proportion of funding to support wider use of proven clean-up technologies:
- EU funding – e.g. Horizon Europe, Cohesion Fund, LIFE, European Maritime and Fisheries Fund, EIB Clean Oceans Initiative
- R&D funding
- Financial support to install technologies

P5: Establish institutional mechanisms to improve coordination/clarify responsibilities between different levels of government (EU, national, regional, local) **and other responsible entities** (e.g. water companies, waste management companies)

P6: Promote active and systematic stakeholder and public engagement in support of robust marine litter policies:
- Create online stakeholder forums or expert advisory groups to the EU institutions (and/or other government bodies)
- Introduce public awareness-raising and engagement programmes highlighting citizens' role in reducing marine litter

Fig. 1. Spreadsheet template for policy assessment.

the EU's broader Circular Economy Action Plan (COM/2015/614 final)[6] and led to the adoption in 2019 of the Single-Use Plastics Directive (2019/904/EU), which targets some of the plastic products that most often become marine litter.

Many national laws, policies and initiatives are also relevant, including national marine strategies, waste legislation, waste management plans, legislation on specific types of plastic waste (e.g. packaging, plastic bags or microbeads), water and waste water legislation, and general environmental strategies. These often stem from the transposition of EU laws into national laws, and meeting the requirements of EU legislation.

Under the CLAIM project, existing policies have been reviewed to identify their aims and see whether other policies might be needed to help to achieve the objectives of the EU marine strategy (Frantzi et al., 2021; van Oosterhout et al., 2021; Watkins et al., 2021).

After this survey, a clear need could be seen for mechanisms to deepen the operationalisation of marine litter actions.

Based on these conclusions a series of additional policy options are proposed that could help to achieve the objectives of the EU MSFD, whilst being complementary to existing policies. Different types of policy options were included, to recognize the different approaches that can be taken by policymakers. They include options related to legislation, financing, institutional coordination and stakeholder engagement. Multiple options could be combined, to create a set of complementary policies to address the marine litter issue.

All the policy options presented next are listed in Fig. 1, emphasizing the most important features of each one.

2.1.1. *Legislative options*

The first policy option (P1) is to develop a specific EU "microplastics Directive". Whilst the EU has a dedicated Single-Use Plastics Directive (2019/904/EU), this is mainly addressed to macroplastics and it does not explicitly cover microplastics. A specific "microplastics Directive" would complement the existing legislation by helping to clarify the EU's objectives on microplastics. It would also provide a useful distinction between macroplastic and microplastic pollution, which would help to encourage governance and technological solutions appropriate to both. Measures that could be included in the Directive could embrace: placing additional restrictions on the use of microplastics in products (especially cosmetics and personal care products (Kentin and Kaarto, 2018)); introducing extended producer responsibility for products likely to emit, or degrade into, microplastics; and allowing for taxation on products likely to emit, or degrade into, microplastics (noting that taxation is more usually a national competence than an EU one). In addition,

[6] https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF

according to a 2018 Report for DG Environment of the European Commission,[7] a 30% reduction by 2035 of microplastic emissions onto surface waters is feasible, provided that a combination of measures to tackle them from pellets, tyres and textiles is implemented. It should be noted that in its annual WorkProgramme for 2022 (COM(2021) 645 final),[8] the European Commission announced its intention to put forward a legislative proposal on measures to reduce the release of microplastics in the environment, scheduled for the final quarter of the year. It remains to be seen what measures will be included in the proposal.

The second policy option (P2) is to revise the Urban Wastewater Treatment Directive (UWTD) ((91/271/EEC) to make it more relevant to addressing microplastics. Revisions that could be considered include: setting limit values on the amount of microplastics that can be present in treated wastewater and sludge; obliging additional treatment steps to remove microplastics (where feasible; possibly only in larger wastewater treatment plants (WTPs)); requiring WTPs to better monitor microplastics (with accompanying guidance on how to do so); and obliging producers to financially support improved wastewater treatment (e.g. through extended producer responsibility). It should be noted that the European Commission held a public consultation on a review of the UWTD during the summer of 2021 (European Commission, 2021a), and plans to make a legislative proposal to review the Directive during the second quarter of 2022.

The third policy option (P3) is to define a set of legislative targets on marine litter and ensure they are fully monitored. This could include: inserting an explicit reference to, and definition of, microplastic and macroplastic marine litter in all relevant EU legislation (either directly in the legislation or by referring to the EU plastics strategy (COM/2018/028/EC) and/or Single-Use Plastics Directive(2019/904/EU); setting new targets to limit the amount of macroplastics and microplastics present in fresh and/or marine waters; and issuing guidance to accompany legislation on tackling marine litter (e.g. on approaches to monitoring). In the body of EU legislation, currently only the Single-Use Plastics Directive includes an explicit reference to microplastic and macroplastic marine litter. Some legislation, such as the MSFD (2008/56/EC) and Waste Framework Directive (2008/98/EC), refer to marine litter only in general terms, with no clear distinction between macroplastics and microplastics. This, together with the absence of these terms from other legislation, such as the Water Framework Directive (2000/60/EC) and the Urban Wastewater Treatment Directive (91/271/EEC), limits policy coherence. A common definition of these types of marine litter across relevant EU legislation and policy would demonstrate the importance of the issue and the EU's desire to act in a coherent way to address it. In addition, the only quantified target for marine litter at present is the threshold value of 20 litter items per 100 m of beach, as defined by the MSFD Technical Group on Marine Litter to support the monitoring of descriptor 10 of the MSFD (Van Loon et al., 2020). Additional complementary targets, together with guidance on monitoring them, would help to better implement the waste prevention objective of the waste hierarchy (2008/98/EC) and the polluter pays principle, creating a drive for action and helping to improve available data.

2.1.2. Financing options

The fourth policy option (P4) is to provide funding to support the wider use of proven clean-up technologies, in particular on public infrastructure such as river estuaries, storm drains and WTP. The proven clean-up technologies are those that present evidence of their effectiveness. This policy option therefore entails R&D funding to demonstrate the effectiveness of innovative technologies that are not yet on the market. At the EU level this could involve mobilizing existing funds such as Horizon Europe (European Commission, 2021b), the Cohesion Funds,[9] LIFE[10] and the new European Maritime, Fisheries and Aquaculture Fund (EMFAF)[11] by allocating a certain amount to clean-up actions.

Governments could consider providing research and development (R&D) grants, subsidies or loans to technology SMEs and start-ups, or financial support also for the installation of technologies. An additional source of finance could be the wider use of economic instruments such as extended producer responsibility (EPR) or product taxes, the revenues from which could be used to support the development of clean-up technologies.

2.1.3. Institutional coordination and stakeholder engagement options

The fifth policy option (P5) is to improve coordination and clarify responsibilities between governments and other entities with a role in marine litter clean-up. Greater clarity on the roles of EU, national, regional and local government bodies and other responsible entities, such as producers, water companies and waste management companies, would ensure that the issue of tackling marine litter does not fall through the cracks.

The sixth and final policy option (P6) is to promote active and systematic stakeholder and public engagement in support of robust marine litter policies. This could involve the creation of more organized structures, for example online forums or expert advisory groups comprising a range of stakeholders such as businesses, citizens' organisations, volunteer groups, NGOs and the research and scientific community. This would provide a legitimate channel for stakeholders to share their insights, knowledge and good practices in support of policy development, implementation and revision. Public awareness-raising campaigns could also play a role in educating individuals about how they can contribute to reducing the problem of macroplastic and microplastic pollution.

It is worth noting that all six additional policy options (P1…P6) are complementary to the existing EU policies. They include critical policies that can be seen as enablers of other interventions, such as the Directive on the reduction of the impact of certain plastic products on the environment (EU) 2019/904 ('Single Use Plastics Directive') and the Marine Strategy Framework Directive 2008/56/EC. Additionally, the policy options P1-P6 are not mutually exclusive and some might act as enablers for other policies. For instance, policy option P1 (to develop a specific EU microplastics directive) could in part contribute to improve coordination and clarify responsibilities (P5), and the involvement of stakeholders (policy option P6 for a systematic stakeholder and public engagement) could be an important enabler to the success of other policies.

2.2. Identifying objectives

The analysis of the objectives pursued in various EU documents allowed to perceive the high-level objectives associated to the EUMSFD. Then a set of key objectives detailing those high-level objectives, for operational purposes, were defined. Together, these objectives address the main areas of concern that are the subject of marine litter policies (mapped in Table 1).

The first area of concern is to address the pollution caused by marine litter, and its impacts on human health, ecosystems and landscapes. The following relevant objectives were defined:

O1. Reducing existing marine litter – microplastics.

O2. Reducing existing marine litter – macroplastics.

[7] https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/pdf/microplastics_final_report_v5_full.pdf

[8] https://eur-lex.europa.eu/resource.html?uri=cellar%3A9fb5131e-30e9-11ec-bd8e-01aa75ed71a1.0001.02/DOC_1&format=PDF

[9] https://ec.europa.eu/regional_policy/en/2021_2027/

[10] https://cinea.ec.europa.eu/life_en

[11] (https://ec.europa.eu/oceans-and-fisheries/funding/european-maritime-and-fisheries-fund-emff_en)

Table 1
Mapping objectives.

Objective	Concerns addressed/included - mapped in (1) to (4)
Reducing existing marine litter (micro and macro plastics) [O1, O2] Preventing new marine litter (micro and macro plastics) [O3, O4]	Achieving or maintaining good environmental status in the Community's marine environment, to continuing its protection and preservation, and to preventing subsequent deterioration (1) To bring about a massive reduction in pollution (2) To protect marine and coastal habitats (2) Achieve significant quantitative reduction of marine litter (3) and prevent further introduction from land/sea sources (3) Reduce marine litter already present (3) Reduce quantities of marine litter (4) Discourage polluters from polluting (4) Improve monitoring of marine litter and related policy targets (4)
Fostering technological innovation, investment, and high-qualified jobs [O5]	To further promote sustainable development (2) Add value to actions on marine litter (3) Encourage technology developers to innovate (4) Promote employment in green/blue technologies (4) Encourage financial investment in new technologies (4)
Generating support among key stakeholders (including EU citizens) [O6]	Make it in the economic interest of those using the marine ecosystems to act in ways which help to achieve the good environmental status objective (1) Communication, stakeholder involvement and raising public awareness (1) Increase social acceptability of clean-up technologies (4) Promote stakeholder engagement and best practice sharing (4) Implement "polluter pays" principle (4)
Producing demonstrable results within a short timespan (years, not decades) [O7]	Increase/speed up implementation/ uptake of clean-up technologies (4) Improve monitoring of marine litter and related policy targets (4)
Ensuring clear duties and responsibilities for implementation [O8]	Ensure that management is coordinated (1) Enhance coordination, cooperation and coherent Implementation (3) Improve coherence of policy on marine litter (4) Improve monitoring of marine litter and related policy targets (4) Clearly define actors' responsibilities (4)

O3. Preventing new marine litter – microplastics.

O4. Preventing new marine litter – macroplastics.

The second area of concern is to consider economic activity related to addressing marine litter. To address this, the following objective was defined:

O5. Fostering technological innovation, investment and skilled jobs.

The third area of concern is the feasibility and effectiveness of marine litter policies. To address this, the following objectives were defined:

O6. Generating support among key stakeholders (including EU citizens).

O7. Producing demonstrable results within a short timespan (years, not decades).

O8. Ensuring clear duties and responsibilities for implementation.

Table 1 sets out a framework for mapping the proposed objectives in key international documents to reflect the main concerns posed by marine litter management that are to be addressed:

(1) The Marine Strategy Framework Directive (MSFD) - Directive 2008/56/EC – considering the effects of Beach litter, Sea Surface litter, Seafloor litter, Micro litter, Biota entanglement, and Litter ingestion
(2) UNEP Mediterranean Action Plan for the Barcelona Convention[12]
(3) The Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM, 2021)
(4) van Oosterhout et al., 2021 and Watkins et al., 2021 (CLAIM Policy Briefs)

2.3. Elicitation

An MCDA process requires assessing the alternatives (in this case, the policies) impact on the multiple criteria (in this case, the objectives), as well as assessing the importance of the criteria. Concerning the impact on the multiple criteria, this is typically performed considering one criterion at a time and using an appropriate quantitative (cardinal) or qualitative (ordinal) scale. In the situation addressed in this work, it would be extremely hard to quantify the impacts of the described policies for the named objectives, and therefore using a qualitative scale with a few levels only was the natural option.

Concerning the assessment of the importance of the criteria (their weights), the MCDA literature offers a wide range of approaches to obtain them in an objective (data-driven) or subjective (informed by decision makers, experts and/or other stakeholders) way. As this work involved a panel of experts and stakeholders, a subjective method needed to be chosen. Among the latter, methods such as AHP (Saaty, 1980) and, more recently, BWM (Rezaei, 2015), FUCOM (Pamučar et al., 2018) or LBWA (Žižović and Pamucar, 2019) elicit weight ratio estimates. Following an earlier work on policy assessment (Dias et al., 2018), we adopt a different approach eliciting direct qualitative importance assessments. This has the advantage of being the most cognitively simple weight elicitation process, although it comes at the cost of not providing an exact weights vector at the end. Rather, it allows multiple weighting vectors compatible with the assessments made, which can be then analyzed with robustness analysis tools, as will be described in Sections 2.4 and 2.5.

The assessment of the policies was based on the elicited perspectives of multiple relevant experts and stakeholders from different countries. To this end, a virtual workshop divided in three parts has been organized to gather their opinion:

Part I - Online session 1: Introduction.

Part II - Offline Survey: Assessing policy contribution to objectives.

Part III - Online session 2: Results and discussion.

Part I was an online meeting to introduce the purpose of the workshop, and also to clarify any questions that might appear. The list of potential policies (P1-P6), as well as the relevant objectives these policies could possibly contribute to (O1-O8), were briefly presented. The spreadsheet template, synthetizing the information described in Sections 2.1 and 2.2 (depicted in Fig. 1) was also explained. Previously to these meetings, a pilot test was performed with a few selected experts, resulting in the incorporation of their suggestions.

Part II consists in collecting the individual perspectives privately, through the spreadsheet template (individual work, offline), providing opinions about how much can each of the policies contribute to each one of the objectives, using a qualitative scale. This ensured that the responses of each participant would not be influenced by the responses of other participants.

The spreadsheet template divided the assessment in two areas:

- The first area contains an assessment about how important each of the objectives is. The answer was provided in a qualitative way,

[12] https://www.unep.org/unepmap/who-we-are/barcelona-convention-and-protocols

choosing one of the following levels for each objective: Not much important (Level 1), Moderately important (Level 2), Very important (Level 3), Extremely important (Level 4).

- The second area contains an assessment about how each policy would potentially impact (contribute to) each objective. In the preparatory meeting, the participants were informed they could make this assessment one objective at a time, seeking to assess the way each policy can potentially contribute to the objective, or one policy at a time, seeking to assess the potential impact of the policy for the different objectives. In either case, the answer was provided in a qualitative way, choosing one of the following levels: Strong negative impact (Level 1), Moderately negative impact (Level 2), Slightly negative impact (Level 3), No impact (Level 4), Slightly positive impact (Level 5), Moderately positive impact (Level 6), Strong positive impact (Level 7).

The responses of the group are aggregated taking into account the qualitative nature of the scales. Indeed, these scales do not allow cardinal operations such as computing a mean value.

The assessments in the first spreadsheet area are aggregated to obtain a ranking of the objectives following the concept of a prudent order. Such a way of aggregating the inputs of a group was proposed by Arrow and Raynaud (1986) and extended to lexicographic prudent orders by Dias and Lamboray (2010). As an example, consider the importance of three objectives *Ox*, *Oy*, and *Oz* was assessed by a group of 20 members. When comparing the assessments in a pairwise fashion one found the following:

- 2 of them placed *Ox* at a higher level than *Oy*, 12 did the contrary, and 6 placed the objectives at the same level;
- 2 of them placed *Ox* at a higher level than *Oz*, 10 did the contrary, and 8 placed the objectives at the same level;
- 4 of them placed *Oy* at a higher level than *Oz*, 1 did the contrary, and 15 placed the objectives at the same level;

Then, if a full ranking was sought, it would be imprudent to propose $Ox \succ Oy \succ Oz$, because 12 of them oppose $Ox \succ Oy$. This could be avoided by proposing $Oy \succ Ox \succ Oz$, but 10 of the group members oppose $Ox \succ Oz$. This could be avoided by proposing $Oy \succ Oz \succ Ox$ or $Oz \succ Oy \succ Ox$. The former includes $Oy \succ Oz$, opposed by 1 member, whereas the latter includes $Oz \succ Oy$, opposed by 4 members. Thus, the prudent order, i.e., the one minimizing the opposition to any comparison implied in it, would be $Oy \succ Oz \succ Ox$. This solution follows the principle that a ranking will be criticized by its weakest link.

The assessments in the second spreadsheet area, concerning the impact of each policy on each objective, are aggregated by considering the median level of the responses for each assessment, i.e., at least half of the members believe the level should not be lower and at least half of the members believe it should not be higher. To observe the robustness of the conclusions obtained with the median, other percentiles are also considered, namely p33 (at least 2/3 of the respondents agree the level should not be lower) and p67 (at least 2/3 of the respondents agree it should not be higher).

Part III was an online meeting in which the aggregate results of the survey have been presented and discussed with the participants.

2.4. ELECTRE TRI rating

A multi-criteria assessment MCDA method is used in this work to assess the policies enumerated above. Many methods can be used for this purpose, among many dozens that have been proposed, and some taxonomies for classifying these methods are available to guide this choice (e.g., Cinelli et al., 2020; Dias et al., 2019; Roy, 1996). Some criteria have been suggested to select a method, such as scientific soundness, feasibility, or degree of compensability, but it is generally acknowledged that no single MCDA method can be considered to be the best one, and the choice is often governed by the familiarity of the users with the method (Cinelli et al., 2014).

For this work, we chose the ELECTRE TRI method, belonging to the ELECTRE family of outranking MCDA methods (Figueira et al., 2013; Govindan and Jepsen, 2016; Dias and Mousseau, 2018). Although this is not the only suitable method that could be used, several reasons made it particularly adequate for the purpose of this work. First, the assessments of the panel are provided on a qualitative scale, and ELECTRE TRI can easily be adapted to work with such assessments without need of transforming these into numbers. Therefore, it avoids making assumptions that would be required to translate the qualitative into quantitative information. A second reason is that ELECTRE TRI aggregates the assessments of each policy independently of the other policies being considered. Therefore, unlike relative evaluation methods, adding, removing, or changing one policy (an alternative or action, in MCDA nomenclature) does not affect the assessment of the remaining policies. A third reason is that ELECTRE TRI has been developed for rating problems (also known as assignment or sorting problems) (Colorni and Tsoukiàs, 2021). It performs an absolute assessment rather than a relative assessment in which policies would be competing against each other. This not only recognizes that these policies are not mutually exclusive, it also provides more information as it can indicate that all policies are good (even the worst one) or that all policies are poor (even the best one). A fourth reason is that ELECTRE TRI is a non-compensatory MCDA method, i.e., a method where having a very poor assessment on one criterion (objective) cannot be compensated by having a very good assessment on some other criterion (Cinelli et al., 2020). Finally, one of the authors already had experience in using this method for an assessment of policies (Dias et al., 2018), among other applications.

The following presentation of ELECTRE TRI is an adaptation, followed in this work, to consider as inputs qualitative levels on a given ordered scale (from Strong negative impact to Strong positive impact) and to provide as an output a qualitative level on the same scale. This presentation also uses the expressions from its application context, "policies" and "objectives", instead of the expressions "actions" and "criteria", respectively, commonly used to present ELECTRE methods. The mathematical notation used in this work is the following:

- m denotes the number of policies being assessed. The set of policies is $P = \{p_1, \ldots, p_m\}$.
- n denotes the number of objectives on which the policies are assessed. The set of objectives is $O = \{o_1, \ldots, o_n\}$.
- k denotes the number of qualitative levels used as inputs (assessment on each objective) and as an output (overall assessment). The set of rating levels is then $L = \{l_1, \ldots, l_k\}$, where l_1 denotes the worst level and l_k denotes the best level, i.e., a level is preferable if its index is greater.
- $a_{ij} \in L$ denotes the qualitative level corresponding to an assessment of policy p_i concerning its impact on (contribution to) objective o_j.

ELECTRE TRI is based on the concept of outranking: a policy $p_i \in P$ is said to outrank a rating $l_b \in L$ (denoted as $p_i S l_b$) if p_i is considered to at least as good as l_b overall, meaning that it deserves to have at least (if not better) the rating level l_b. The following steps are followed to conclude if $p_i S l_b$:

1. Define the concordance of objective o_j with the conclusion $p_i S l_b$ as

$$c_j(p_i, l_b) = \begin{cases} 1, & \text{if } a_{ij} \text{ is equal to or better than } l_b \\ 0.5, & \text{if } b > 1 \text{ and } a_{ij} \text{ is equal to } l_{b-1} \\ 0, & \text{if } b > 2 \text{ and } a_{ij} \text{ is worse than } l_{b-1} \end{cases}$$

(Note: this adaptation mimics the original ELECTRE TRI when levels

correspond to integer numbers, the indifference threshold is null and the preference threshold equals 2).

2. Define the overall concordance of the n objectives with the conclusion $p_i S l_b$ as

$$C(p_i, l_b) = \sum_{j=1}^{n} w_j c_j(p_j, l_b)$$

where $w_1, \ldots, w_n$ define a weighting vector $\mathbf{w} = (w_1, \ldots, w_n)$ representing the relative importance of each objective. This vector is such that all elements are positive and the sum of the elements is equal to one.

3. Define optionally a veto condition, specifying for each level l_b and for each objective o_j, a minimum performance level v_{bj} to allow $p_i S l_b$. Then, define discordance as

$$d_j(p_i, l_b) = \begin{cases} 0, & \text{if } v_{bj} \text{ is not defined, or if } a_{ij} \text{ is equal to or better than } v_{bj} \\ 1, & \text{if } a_{ij} \text{ is worse than } v_{bj} \end{cases}$$

4. Define the credibility of the outranking as (Mousseau and Dias, 2004):

$$s(p_i, l_b) = C(p_j, l_b) \prod_{j=1}^{n} (1 - d_j(p_j, l_b))$$

5. Make a conclusion about the outranking as:

$$p_i S l_b \Leftrightarrow s(p_i, l_b) \geq \lambda$$

where λ is a parameter that indicates the required majority, acting as a cutting level. The higher the required majority, the harder it is to warrant an outranking. Usually, λ assumes a value between 0.5 (a simple majority of the objectives, taking their weight into account) and 1 (requiring unanimity of the objectives).

Based on the outranking relation the global rating of a policy will be the highest one the policy can outrank, corresponding to the more conservative variant of ELECTRE TRI:

- policy p_i is rated l_b, for some $b<k$) if and only if $p_i\ S l_b$ but not $p_i\ S l_{b+1}$;
- policy p_i is rated l_k if and only if $p_i\ S l_k$.

The results of MCDA methods are influenced by the parameters they use, in particular the weights, but also in this case the cutting level. Sensitivity analysis or robustness analysis can be used to study the influence of these parameters (Dias and Clímaco, 2000): sensitivity analysis usually departs from an initial vector of exact parameter values and then studies the stability of the result obtained when this vector changes, whereas robustness analysis does not require setting an initial vector of parameters and studies the set of results that corresponds to a given subspace of the parameters values set.

In this study, no specific values were set for the weighting vector $\boldsymbol{w}$ and the cutting level λ. Instead, a robustness analysis perspective was adopted by computing the best and worst possible results for each policy, considering only a ranking of the weights and an interval for λ, following the method of Dias and Clímaco (2000).

2.5. Ranking based on stochastic rating

To obtain a ranking of the policies in terms of relative priority, in case such a result is sought, the process should be compatible with the rating method. One possibility to obtain such a ranking is to compare policies with the same rating, say l_b, based on the outranking credibility $s(p_i, l_b)$, as suggested by Dias et al. (2018). One can also use a SMAA TRI stochastic approach (Tervonen et al., 2007), to obtain, for each policy p_i, the probability $P(p_i$ is rated $l_b)$, for all levels l_b, by means of a Monte-Carlo simulation. This simulation samples random weighing vectors and cutting levels following a uniform distribution within specified bounds. The output of SMAA TRI complements the information about the best and worst possible results for each policy obtained by Dias and Clímaco's method by indicating which ratings are more likely within that interval. Then, policies can be ranked following a metaweights SMAA-2 approach (Lahdelma and Salminen, 2001) ranking first the policies that are more likely to have the highest ratings. This was the approach followed in the present study.

3. Application and results

The panel participating and providing inputs for this study was comprised by twenty-three experts and stakeholders concerning plastic litter in European seas. The panel (12 men, 11 women) included a group of academic experts (8 persons affiliated with universities and research centers), a group of industry experts (4 persons working at consulting firms and a company), and a group from authorities (11 persons from the European Commission, government agencies, regional authorities, municipalities, and port authorities), working from Belgium, France, Germany, Greece, Oman, Portugal, Spain and the United Kingdom.

Fig. 2 summarizes the perspectives of the panel members concerning the importance of the objectives (data available in Appendix A). Objectives O3 and O4 stand out as being considered the most important ones, followed by O1 and O2. The main difference observed between the groups listed above is that only 50% of the industry experts indicate O6 "Very important" or "Extremely important", whereas all academic experts and 82% of the members from authorities indicated these importance levels.

Table 2 presents the median of the assessments concerning the impact of each policy on each objective (data available in Appendix A). The main differences observed between the groups, in terms of medians, are the following (in the remaining cases the medians coincide or differ by a single level):

- only 25% industry experts estimate positive impact (at least slightly) of policy P2 on objective O2 and on objective O4 vs. 91% of the members from authorities;
- only 25% industry experts estimate positive impact (at least slightly) of policy P4 on objective O8 vs. 62.5% of the academic experts and 91% of the members from authorities.

ELECTRE TRI can now be applied to rate the $m = 6$ policies considering the $n = 8$ objectives and the median assessments. According to these median assessments, all the policies have an impact at least slightly positive for all the objectives. For this reason, no reasons were found to model the possibility of veto in ELECTRE TRI, i.e., having a Slightly positive impact (l_5) on some objective was not found to be sufficiently weak to veto even the top rating level l_7. Therefore,

$$\forall p_i \in P, l_b \in L, d_j(p_i, l_b) = 0, \text{which implies } s(p_i, l_b) = C(p_i, l_b) = \sum_{j=1}^{n} w_j c_j(p_j, l_b)$$

As such, the overall rating of each policy is based on the concordance levels $c_j(.)$ for the different objectives, presented in Table 3. The outranking relations then depend on the weighting vector $\mathbf{w}$ and the required majority λ. From Table 3, for all policies, all objectives are unanimous in their concordance to achieve at least rating l_5. For policies p_2, p_3 and p_4, all objectives are unanimous in their concordance to achieve at least rating l_6. All other conclusions depend on the ELECTRE TRI parameters. For instance, policy p_1 can reach rating l_6 if the weight of the second objective is not too high and λ is not too high either (more precisely, if $1\text{-}w_2 \geq \lambda$), and can reach rating l_7 if the weight of the second

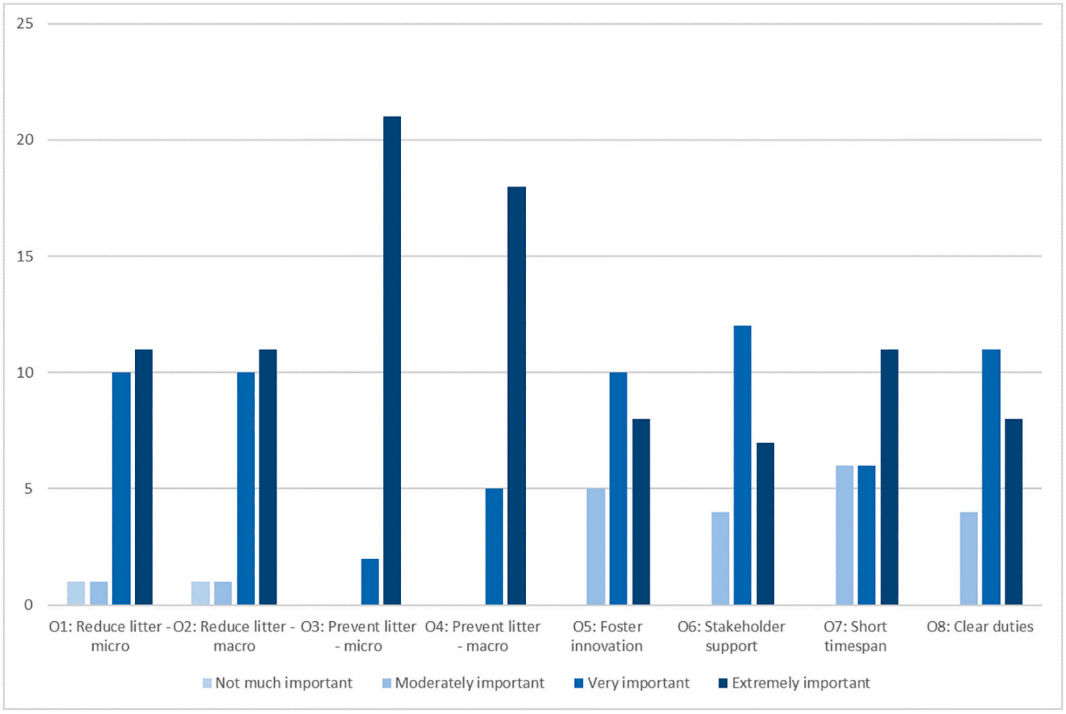


Fig. 2. Responses of the panel concerning the importance of the objectives.

Table 2
Assessments (median) of the panel concerning the impact of policies on objectives.

	P1: microplastics directive	P2: urban WWT directive	P3: targets & monitoring	P4: fund clean-up tech	P5: coordination	P6: engagement
O1: Reduce litter - micro	Strong positive	Strong positive	Strong positive	Strong positive	Moderately positive	Moderately positive
O2: Reduce litter - macro	Slightly positive	Moderately positive	Strong positive	Strong positive	Moderately positive	Moderately positive
O3: Prevent litter - micro	Strong positive	Strong positive	Strong positive	Strong positive	Moderately positive	Moderately positive
O4: Prevent litter - macro	Moderately positive	Moderately positive	Moderately positive	Strong positive	Moderately positive	Moderately positive
O5: Foster innovation	Moderately positive	Moderately positive	Moderately positive	Strong positive	Moderately positive	Slightly positive
O6: Stake-holder support	Moderately positive	Moderately positive	Moderately positive	Moderately positive	Moderately positive	Strong positive
O7: Short timespan	Moderately positive	Moderately positive	Moderately positive	Moderately positive	Slightly positive	Slightly positive
O8: Clear duties	Moderately positive	Moderately positive	Moderately positive	Moderately positive	Strong positive	Moderately positive

objective is low, the weight of the first and third objectives is high, and λ is low.

Rather than allowing complete freedom of the weights **w** and the required majority λ, these were bound by a few reasonable constraints. First, the required majority was bounded to λ∈[0.65, 0.85], i.e. an interval centered on a required majority of 3/4 of the objectives plus or minus 0.10. Then, weight constraints were added to respect the prudent order corresponding to the responses of the panel members when rating the importance of the objectives (Table 4):

$$w_3 \geq w_4 \geq w_2 \geq w_1 \geq w_6 \geq w_7 \geq w_5 \geq w_8$$

This order is prudent in that at most 6 of the 23 panel members oppose to any of the comparisons implicit in the order.

The minimum and maximum ELECTRE TRI rating that each policy can have with and without these constraints is provided in Table 5. These results were obtained using the IRIS software (Dias and Mousseau, 2003). These results suggest organizing policies in two groups: a group formed by the most potentially impactful policies p_2, p_3, and p_4 and a group formed by the remaining policies p_1, p_5, and p_5.

As a means to further discriminate these policies, the ELECTRE TRI analysis was complemented with a SMAA TRI stochastic analysis using the jSMAA software (Tervonen, 2014). This analysis considers the same constraints as above, i.e., the ranking of the weights and the interval for the required majority. The results and the respective ranking of the policies are presented in Table 6. Considering the results for ranked weights and λ∈[0.65, 0.85], the most potentially impactful policy is p_4 followed by p_2 and p_3. Coincidently, the ranking based on the SMAA TRI results is the same if no constraints are considered.

To analyze the sensitivity of these results to the option of selecting the median assessments, the analysis was repeated considering a more pessimistic and a more optimistic assessment. The pessimistic assessment consisted in the percentile 33 of the assessments, i.e., assessments such that less than 1/3 of the panel members consider it should be lower. The optimistic assessment consisted in the percentile 67 of the assessments, i.e., assessments such that less than 1/3 of the panel members consider it should be higher.

Table 3
Concordance of the objectives with obtaining at least a given rating.

Policy	Concordance for rating…	O1	O2	O3	O4	O5	O6	O7	O8
P1	l_7	1	0	1	0.5	0.5	0.5	0.5	0.5
	$\geq l_6$	1	0.5	1	1	1	1	1	1
	$\geq l_5$	1	1	1	1	1	1	1	1
P2	l_7	1	0.5	1	0.5	0.5	0.5	0.5	0.5
	$\geq l_6$	1	1	1	1	1	1	1	1
	$\geq l_5$	1	1	1	1	1	1	1	1
P3	l_7	1	1	1	0.5	0.5	0.5	0.5	0.5
	$\geq l_6$	1	1	1	1	1	1	1	1
	$\geq l_5$	1	1	1	1	1	1	1	1
P4	l_7	1	1	1	1	1	0.5	0.5	0.5
	$\geq l_6$	1	1	1	1	1	1	1	1
	$\geq l_5$	1	1	1	1	1	1	1	1
P5	l_7	0.5	0.5	0.5	0.5	0.5	0.5	0	1
	$\geq l_6$	1	1	1	1	1	1	0.5	1
	$\geq l_5$	1	1	1	1	1	1	1	1
P6	l_7	0.5	0.5	0.5	0.5	0	1	0	0.5
	$\geq l_6$	1	1	1	1	0.5	1	0.5	1
	$\geq l_5$	1	1	1	1	1	1	1	1

Table 4
Number of the respondents who oppose to considering the objective in the row at least as important as the objective in the column.

	O3	O4	O2	O1	O6	O7	O5	O8
O3		1	2	1	0	1	0	0
O4	4		2	3	0	2	1	0
O2	12	10		1	3	4	3	3
O1	11	10	1		3	5	3	3
O6	15	12	7	7		6	4	5
O7	11	11	9	7	7		6	6
O5	13	11	10	10	4	7		6
O8	14	12	7	7	5	5	7	

Table 5
Minimum and maximum ELECTRE TRI rating for each policy with and without constraints.

Policy	No constraints on **w** or λ		Ranked weights and λ∈[0.65, 0.85]	
	Minimum	Maximum	Minimum	Maximum
Microplastics directive (p_1)	l_5	l_7	l_5	l_7
Urban WWT directive (p_2)	l_6	l_7	l_6	l_7
Targets & monitoring (p_3)	l_6	l_7	l_6	l_7
Fund clean-up tech (p_4)	l_6	l_7	l_6	l_7
Coordination (p_5)	l_5	l_7	l_6	l_6
Engagement (p_6)	l_5	l_7	l_6	l_6

Table 6
Rating probabilities according to SMAA TRI and resulting ranking for the policies considering median assessments.

Policy	No constraints on **w** or λ			Ranked weights and λ∈[0.65, 0.85]			Rank
	$P(l_5)$	$P(l_6)$	$P(l_7)$	$P(l_5)$	$P(l_6)$	$P(l_7)$	
Microplastics directive (p_1)	0.03	0.81	0.16	~0	0.91	0.09	4th
Urban WWT directive (p_2)	0	0.75	0.25	0	0.63	0.37	3rd
Targets & monitoring (p_3)	0	0.63	0.37	0	0.25	0.75	2nd
Fund clean-up tech (p_4)	0	0.37	0.63	0	0	1	1st
Coordination (p_5)	0.06	0.88	0.06	0	1	0	5th
Engagement (p_6)	0.15	0.81	0.03	0	1	0	6th

The p33 and p67 assessments are indicated in Table 7. Among the $8 \times 6 = 48$ assessments, the pessimistic and pessimistic ones coincided in 8 cases. In most cases (29), the pessimistic assessment is one level below the optimistic assessment. In a few more contrasting cases (8), the pessimistic assessment is two levels below the optimistic assessment. The global picture is still one of a positive assessment. Even in the pessimistic (p33) assessment, all impacts are at least slightly positive, except four "No impact" assessments.

The results for the extremes of these intervals are presented in Table 8. Considering the pessimistic (p33) assessments, all policies are rated l_5 or l_6. Policies p_3 and p_5 are 100% in l_6, whereas the previously first-ranked policy p_4, drops to the fourth position, although remaining more likely to be l_6 than l_5. Another policy previously in the top 3, policy p_2, drops to the last position. Considering the optimistic (p67) assessments, all policies are rated l_6 or l_7. Policies p_3 and p_4 are 100% in l_7, and p_2 is 99% in l_7.

In summary, the median assessments lead to identifying all policies as impacting positively the policy objectives, and this remains valid even if the p33 assessments are considered instead, denoting a high level of consensus about the interest of implementing these policies.

The median assessments suggest the higher priority policies would be p_2, p_3, and p_4. However, p_4 and especially p_2 have some weaknesses that make them appear as less impactful when p33 assessments are considered. In particular, the assessments of p_4 suggest paying particular attention to the need to fund technologies for microplastics (regarding O4) and the need to meet concerns about who is responsible for what (regarding O8); the assessments of p_2 suggest paying particular attention to macro-plastic pathways to rivers and seas (regarding O2) and the need to meet concerns about producing results quickly (regarding O7).

The median assessments suggest the lower priority policies would be p_1, p_5, and p_6, mainly for their less stellar assessments on some of the most important objectives. Policy p_1 is hindered by not directly addressing microplastic litter, but its strengths on objectives O1 and O3 related to microplastic can make it interesting to complement the other policies. Policies p_5 and p_6 are among the best when considering p33 assessments and can also be very useful to complement the other policies, namely considering p_5's strength on O8 (the most impactful for this objective) and p_6's strength on O8 (the most impactful for this objective).

These results were analyzed by stakeholders and experts in Part III of the workshop mentioned in Section 2.3. The soundness of the policy options proposed to tackle the EU marine strategy becomes clear. It is worth noting that policy options were evaluated against objectives

Table 7
Assessments range (percentiles p33 – p67) of the panel concerning the impact of policies on objectives.

Range p33-p67	P1: Micro-plastics directive	P2: Urban WWT directive	P3: Targets & monitoring	P4: Fund clean-up tech	P5: Coordi-nation	P6: Engage-ment
O1: Reduce litter - micro	Moderately positive - Strong positive	Moderately positive - Strong positive	Moderately positive - Strong positive	Moderately positive - Strong positive	Moderately positive	Slightly positive - Moderately positive
O2: Reduce litter - macro	No impact - Moderately positive	No impact - Moderately positive	Moderately positive - Strong positive	Moderately positive - Strong positive	Moderately positive	Slightly positive - Moderately positive
O3: Prevent litter - micro	Strong positive	Strong positive	Moderately positive - Strong positive	Slightly positive - Strong positive	Moderately positive - Strong positive	Moderately positive - Strong positive
O4: Prevent litter - macro	Slightly positive - Moderately positive	Slightly positive - Strong positive	Moderately positive - Strong positive	Moderately positive - Strong positive	Moderately positive - Strong positive	Moderately positive - Strong positive
O5: Foster innova-tion	Moderately positive	Moderately positive - Strong positive	Slightly positive - Moderately positive	Strong positive	Slightly positive - Moderately positive	Slightly positive - Moderately positive
O6: Stake-holder support	Slightly positive - Moderately positive	Slightly positive - Moderately positive	Slightly positive - Strong positive	Slightly positive - Strong positive	Slightly positive - Strong positive	Moderately positive - Strong positive
O7: Short time-span	Moderately positive - Strong positive	Slightly positive - Strong positive	Slightly positive - Strong positive	Moderately positive - Strong positive	Slightly positive - Moderately positive	Slightly positive - Moderately positive
O8: Clear duties	Moderately positive - Strong positive	Moderately positive	Slightly positive - Strong positive	No impact - Moderately positive	Strong positive	Slightly positive - Moderately positive

Table 8
Rating probabilities according to SMAA TRI considering p33 and p67 assessments.

Policy	p33				p67			
	$P(l_5)$	$P(l_6)$	$P(l_7)$	Rank	$P(l_5)$	$P(l_6)$	$P(l_7)$	Rank
Microplastics directive (p_1)	0.63	0.37	0	5th	0	0.45	0.55	6th
Urban WWT directive (p_2)	0.72	0.27	0	6th	0	0.01	0.99	3rd
Targets & monitoring (p_3)	0	1	0	1st	0	0	1	1st
Fund clean-up tech (p_4)	0.37	0.63	0	4th	0	0	1	1st
Coordination (p_5)	0	1	0	1st	0	0.15	0.85	4th
Engagement (p_6)	0.19	0.81	0	3rd	0	0.19	0.81	5th

mapped in key international documents that reflected the main concerns posed by marine litter management, particularly the Marine Strategy Framework Directive (Section 2.2, Table 1). This meeting serves as a validation process, given the detailed discussion that preceded it and the deep involvement of a significant group of experts and stakeholders.

4. Conclusions

The EU's Marine Strategy Framework Directive (MSFD), adopted in 2008, sets the framework for action to protect the EU's marine waters. It had the overarching objective of achieving Good Environmental Status (GES) of those waters by 2020, thereby protecting the resource that supports marine-related economic and social activities.

The MSFD was not only the first EU law dealing specifically with the protection of marine biodiversity, but also the first to explicitly address the issue of marine litter. Its Annex I includes marine litter as one of the key indicators to be monitored to assess GES for all European seas and the effectiveness of policy measures. This takes the form of Descriptor 10: Marine litter, which states that by 2020 the "Properties and quantities of marine litter do not cause harm to the coastal and marine environment". The monitoring of Descriptor 10 is supported by what is currently the only quantified EU target for marine litter, namely a threshold value of 20 litter items per 100 m of beach, as defined in 2020 by the MSFD Technical Group on Marine Litter. The European Commission published its first report on the implementation of the MSFD in 2020. It acknowledged that marine litter was a major issue with plastic litter, in particular, needing much more effective action.

Given the attention focused on the issues set out in the MFSD report, which reflect the areas of concern in current EU legislation, and other key international documents expressing the same concern (Table 1), further policy options were proposed that were intended to encourage much more effective action. A range of policy options were indicated so that the various approaches open to policymakers could be covered. They include options related to legislation, financing, institutional coordination and stakeholder engagement. Several options could be combined to create a set of complementary policies to deal with marine litter. The analysis of the objectives pursued in various EU documents made it possible to grasp the high-level objectives associated with the EU MSFD. Then a set of key objectives were defined, detailing those high-level objectives, for operational purposes. Together, these objectives address the main areas of concern that should be the subject of marine litter policies. An MCDA framework has been developed to evaluate policy options so that they can be rated and ranked to establish recommendations for the EU as to the most promising policies that would really help to meet the objectives of its marine litter strategy.

In light of all the assumptions included in the framework mentioned in the previous paragraph, it can be stated that the results drive the prioritization of policies that are likely to promote proactive actions to enhance the implementation of the EU marine strategy.

The methodology followed to assess the policies successfully met the goals for this research: to allow the participation of experts and stakeholders in marine plastic debris, who are not necessarily experts on MCDA; to allow these participants to express their views using only qualitative assessments; and to observe the emergence of some consensus despite the diversity of perspectives that inevitably coexist in a group. The emerging consensus deems that all the policies deserve to be considered for their overall positive impacts on the policy objectives, even when the more pessimistic assessments (the 33rd percentile) are used. This is a conclusion that is robust to changes in the weighting vector and the required majority level. Not all policies were considered equally impactful though. Policies P2 (Revision of Urban WWT directive), P3 (Targets and monitoring) and P4 (Fund clean-up technologies) were on the whole better evaluated than policies P1 (Microplastics directive), P5 (Coordination) and P6 (Stakeholders engagement). The latter policies are nevertheless particularly strong for some of the objectives, and therefore can play an important role in complementing the higher-ranked policies. These results bring a variety of actions into the spotlight. In fact, policy 2 (P2) is about revising the Urban Wastewater Treatment Directive by setting limits on the amount of microplastics that can be present in treated wastewater and sludge, probably requiring further treatments and monitoring and obliging producers to accept an additional financial effort. Furthermore, in policy 3 (P3) marine litter monitoring (for micro and macroplastics) and EU legislation is clearly

needed, as well as the inclusion of the reference to EU Plastics Strategy and Single Use Plastics (SUP) Directive in all pieces of legislation. Funding the implementation of innovative technologies (P4) is also an important issue for the panel of experts and stakeholders. In Fig. 1 (and Sections 2.1 and 2.2) more detailed information about impacts of the various policies is highlighted and the potential actions are underlined in each policy prioritized.

On 2 March 2022, at the 5th meeting of the United Nations Environment Assembly (UNEA) of the United Nations Environment Programme (UNEP), 175 nations agreed on a resolution[13] to create an international, legally binding agreement to end plastic pollution by 2024, as there is a risk posed to human and environmental health. Even though the approval was granted after the organization of the workshop for the multi-criteria decision analysis described in this article, our findings are well aligned with the UNEA Resolution. Indeed, our findings show the importance of implementing policies that will make it possible to better target microplastics (by setting various limitations on microplastics entering the environment in a revised version of the Urban Wastewater Treatment Directive), to set legislative targets on marine litter (microplastics and macroplastics) and ensure they are fully monitored, and to fund innovative technologies.

The 2018 European Strategy for plastics, as part of the EU's circular economy action plan, introduced measures to reduce plastic waste (e.g. the 2019 SUP Directive) and proposed a list of future EU measures to implement the Strategy. Another list of measures is recommended to national authorities and industry including, for example, to take domestic action to reduce the leakage of plastics in the environment, prevent plastic waste and increase recycling.[14] This work has demonstrated that all the policies proposed can contribute to the implementation of a more robust EU Strategy for plastics to protect the environment and reduce marine litter. In fact, their assessment led to identifying all policies as having a positive impact on the policy objectives pursued in various EU documents associated with the EU MSFD. This notably includes the objectives of reducing plastic litter and microplastics in the environment and contributing to improved data on microplastic concentrations in seawater. The policies clearly reach a high level of consensus from the experts and stakeholders' panel. The measures envisaged for the implementation of these policies (Fig. 1) mean that the EU can take a lead in implementing a transition to a circular economy by keeping plastic and its value in the economy and out of the ocean.

The authors hope this paper contributes to deal with marine litter new challenges for public policy design, to explicitly make sound recommendations for real-world informed decisions.

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CRediT authorship contribution statement

Luis C. Dias: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Maria C. Cunha:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Emma Watkins:** Conceptualization, Investigation, Data curation, Writing – original draft, 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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Appendix A. Supplementary data

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