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Optimizing waste management for green shipping: industry commitment through participatory processes in Cyprus

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Abstract

Every year, up to 0.3 million tonnes of waste from the European shipping industry is not properly delivered at ports. Most of the waste produced by the shipping industry is plastic waste, putting plastics at the forefront of the shipping industry's waste management efforts. In an increasingly connected global economy, concerted actions that encourage and incentivise waste minimisation and waste management optimisation are essential for the reduction of marine litter and the achievement of a circular economy within the shipping industry. Cyprus, an important flag state, can take a leadership role towards this direction. This article presents the results of the implementation of the DeCyDe-4-Shipping decision-support participatory method in Cyprus, which allowed effective multi-stakeholder interactions and resulted in the identification of actions for waste minimisation and waste management optimization that are relevant, effective, implementable, and stem from stakeholder consensus. The method resulted in the definition of yearly action plans with prioritized actions and provided the tools through which to monitor the industry's annual progress. As the shipping industry is dependent on a global supply chain, DeCyDe-4-Shipping could be replicated at a wider geographic scale, starting with Mediterranean ports, to ensure consistent industry progress towards waste minimization and waste management optimization.

Keywords: Sustainable shipping, Mediterranean, Waste management, Waste minimization, Plastic pollution

Introduction

Every year, in the European Union, between seven and thirty-four percent of ship-related waste, amounting to between 60,000 and 300,000 tonnes, is not delivered at ports (European Commission 2018), and by extension is likely lost or disposed of at sea. The most common type of waste from the shipping industry is plastic (Moheea et al. 2012). Marine litter, and especially plastic marine litter, poses a serious threat to marine ecosystems and to human health, and serious economic damages to tourism, fishing, and shipping (Boucher and Bilard 2020). Plastic consumption and plastic waste minimization efforts should therefore be at the forefront of the shipping industry's waste management and marine litter reduction efforts.

The management of ship waste has consistently been among the top ten environmental priorities of European ports since 2013 (European Sea Ports Organization [ESPO], 2022). However, shipping is a global industry, making waste management optimisation particularly challenging, as the legislative framework and implemented practices vary significantly between home ports and ports of call across the world. The International Maritime Organization's Marine Pollution Convention (MARPOL) is the main international policy instrument concerning ship waste management at sea. MARPOL mandates minimum waste segregation and management requirements in its Annex V, which, inter alia, completely prohibits the disposal of plastic waste at sea. Nonetheless, proper waste segregation onboard is often inadvertently disincentivized by the lack of proper waste segregation at port reception facilities (European Commission 2018). This issue is addressed by the Port Reception Facilities Directive (European Union 2019) which focuses on what happens to ship waste once it comes on land. The 2019 amendment of the Port Reception Facilities Directive aims to harmonize the Directive with the provisions of the International Maritime Organization and MARPOL, and to better align it with other advancements in European policy, including the 2018 revision of the Waste Framework Directive and the EU Circular Economy policy.

In an increasingly connected global economy, the development of fit-for-purpose port reception facilities that encourage and incentivise waste minimization and waste management optimization, both onboard and at port, is a mandatory prerequisite to the achievement of a circular economy within the shipping industry. In recent years, several European ports, such as Amsterdam, Hamburg and Antwerp, have taken significant steps in optimizing waste management, as part of their efforts to apply the circular economy approach (Karimpour et al. 2019). The number of ports implementing more sustainable practices is increasing (ESPO 2022), however there is still significant work to be done, and the entire shipping value chain should be involved. Coordination and communication among the key bodies involved in waste management, including state authorities such as port authorities and ship management companies, is instrumental to ensuring that there is in place an effective waste management system, both on board and at ports (Kyramargiou and Vardopoulos 2019; Spadaro et al. 2021).

Cyprus, as a pivotal flag state, plays a significant role in global maritime operations. The nation boasts a robust merchant fleet, totalling approximately 24 million gross tonnage, making it the third-largest registry within the European Union and the eleventh-largest globally (Shipping Deputy Ministry [SDM] 2020). Notably, around 87% of shipping companies established in Cyprus are under the control of Cypriot or EU interests, underscoring the nation's maritime prominence (SDM 2020). Moreover, Cyprus predominantly relies on short sea shipping, which constitutes over 90% of its seaborne transport, with Limassol Port serving as a crucial transhipment hub (Michaelides et al. 2019).

In terms of port infrastructure, the Republic of Cyprus oversees six operational ports, with New Limassol Port and Larnaca Port emerging as the principal maritime gateways. New Limassol Port holds distinction as the largest and most pivotal port, catering to both passenger and commercial traffic. The port's operations are augmented by two private management entities, Eurogate Container Terminal Limassol Limited, responsible for managing the container terminal, and DP World Limassol Limited, overseeing both

the trading and cruise terminals. Meanwhile, Larnaca Port, currently undergoing redevelopment, is poised to serve cruise ships and meet local commercial demands upon completion of its reconstruction phase.

Among the remaining ports, Old Limassol Port, Pafos Port, and Latchi Port primarily accommodate fishing boats and leisure vessels, while Zygi Port serves as an industrial hub, hosting various jetties and terminals, including those operated by Vassiliko Cement Works for the export of clinker and cement, VTTV for hydrocarbon loading and unloading, M.A. Skyra Vassas for the export of quarry products, and the Cyprus Electricity Authority for electricity production purposes. Additionally, the presence of marinas across the island further augments Cyprus's maritime infrastructure, with ongoing governmental initiatives aimed at bolstering maritime tourism through the construction of additional marinas under long-term agreements with private operators.

Following the intricate web of maritime infrastructure in Cyprus, waste management emerges as a critical facet of port operations and environmental stewardship within the nation's maritime sector. The efficient handling and disposal of waste not only uphold environmental standards but also contribute to sustainable maritime practices. With Cyprus's pivotal role in global maritime operations, an examination of waste management practices becomes imperative to comprehensively assess the industry's environmental footprint and its alignment with evolving regulatory frameworks.

Under the oversight of the Cyprus Port Authority, waste management operations at Cypriot ports are meticulously coordinated, with licensed contractors tasked with the collection and disposal of specific types of hazardous and municipal waste generated from port activities and vessels. Despite the systematic approach to waste management, limited detailed information is available regarding the precise composition and volume of waste generated and managed within Cypriot ports. However, estimates suggest that circa 15,000 cubic metres of solid waste are collected annually at Cypriot ports (https://www.marlisco.eu/Indirect_fee_system_for_the_collection_of_ship_waste_in_Cyprus.en.html), highlighting the significance of effective waste management protocols in mitigating environmental impacts.

As the maritime industry navigates towards greater sustainability, addressing waste management practices becomes paramount. Sustainability and reporting against the shipping industry's performance is necessary to create value and growth opportunities for the industry (Di Vaio et al. 2020). Achieving sustainability goals necessitates not only stringent adherence to regulatory requirements but also proactive efforts to minimize waste generation and optimize waste management processes. Amidst this landscape, the Cypriot shipping industry emerges as a potential catalyst for driving environmental stewardship and fostering the transition towards a green and circular economy. However, while considerable attention has been devoted to decarbonization initiatives within the Cypriot shipping industry (e.g. Nisiforou et al. 2022), research focusing on waste minimization and optimization of waste management practices remains relatively sparse.

In light of the growing emphasis on sustainability and regulatory compliance within the shipping industry, there exists an imperative to bridge this knowledge gap and explore avenues for enhancing waste management practices. By fostering a deeper understanding of the challenges and opportunities inherent in waste management

within the Cypriot maritime sector, stakeholders can collectively work towards implementing holistic strategies that reconcile environmental stewardship with operational efficiency. This endeavour not only aligns with the broader objectives of sustainability and regulatory compliance but also unlocks new avenues for value creation and growth within the shipping industry, both domestically and internationally.

This article identifies (1) the practices that the Cypriot shipping industry, along its entire value chain, is implementing to minimize waste production and optimise waste management, (2) the main gaps and needs that the Cypriot shipping industry is facing and which are hindering progress regarding waste minimization and waste management optimization, and (3) the solutions that could be implemented to address these gaps and needs. The method implemented resulted in the development of the first Cypriot Action Plan for Waste Management in Shipping.

Section "Methods" presents the method used to engage the stakeholders in the process of designing the Action Plan. This consisted of participatory processes implemented in two consecutive years. The results are presented and discussed in "Results and discussion" section, which is split into four subsections; "Participating stakeholders" section presents the stakeholders that participated in the workshops, "Outputs from 2021, the first year of implementing DeCyDe-4-Shipping: the baseline study" section presents the outputs from the first iteration of the participatory process, which resulted in an initial Action Plan and formed the baseline study for the shipping industry's waste management practices, "Outputs from the 2022 DeCyDe-4-Shipping implementation: progress monitoring and updated action plan" section presents the outputs from the second iteration of the participatory process and the resulting Action Plan, whereas "Stakeholder perceptions on the method, the action plan and the way to take it forward" section presents the perceptions of the stakeholders regarding the implemented process. The conclusions are presented in "Conclusions" section.

Methods

Stakeholder engagement through structured decision-making processes that result in understanding and recording of perceptions, needs and proposed solutions is paramount to developing sound and publicly accepted policies (Burger et al. 2016; Loizidou et al. 2016, 2017, 2021; Stringer et al. 2007). Decision-making that follows participatory practices can also build capacity and foster trust and collaboration between the involved stakeholders (Muro and Jeffrey 2008). There are several participatory techniques identified in literature, each resulting in varying levels of stakeholder engagement and involvement (Luyet et al. 2012). In this study, the DeCyDe-4 method and tools were implemented to engage stakeholders in the decision-making process concerning waste minimization and waste management optimization in the Cypriot shipping industry, since it is an adaptable, site- and case-specific decision-support method that leads to informed, science-based, and justifiable decisions on issues relating to sustainability and resilience (Loizidou et al. 2014).

DeCyDe-4 was developed by ISOTECH's experts in participatory, solution-oriented decision-making processes and stakeholder involvement facilitation. The DeCyDe-4 method has been extensively described by Loizidou et al. (2016, 2017, 2021) and Schumacher et al. (2018) and successfully used in stakeholder engagement processes that

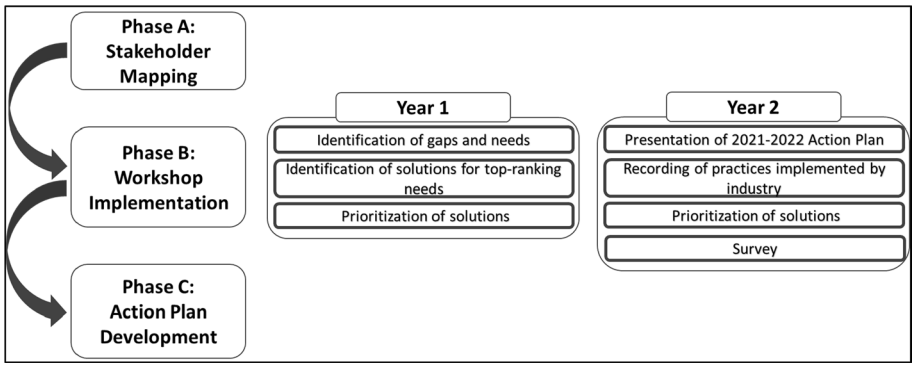

Fig. 1 Schematic of the DeCyDe-4-Shipping method

resulted in the development of action plans and policy tools in diverse geographic locations for a variety of topics, including coastal management, marine litter management and sea level rise. The initials "DeCyDe" are a play on the word "decide" where "ci" has been replaced by "Cy", which stands for Cyprus, the country where ISOTECH is based. The suffix "-4" stands for the word 'for' and is included to denote the fact that the main "DeCyDe" method is adapted to meet the specificities of each decision-making problem at hand, forming dedicated "DeCyDe-4" tools (Loizidou et al. 2023). In this specific study, DeCyDe-4 was adapted to develop the DeCyDe-4-Shipping version and associated tools.

DeCyDe-4-Shipping was designed specifically for the development of solution-oriented action plans for solid waste management in the shipping industry. The method was first implemented in Cyprus over two consecutive years, 2021 and 2022. The first year of implementation (2021) served as the baseline study, a first scan for the identification of the problems of the industry related to waste minimization and waste management optimization and resulted in the development of the 2021–2022 Cypriot Action Plan for Waste Minimization and Waste Management Optimization in Shipping. In the second year of implementation (2022), progress was monitored, and the 2022–2023 Action Plan was developed.

DeCyDe-4-Shipping is structured in three phases (Fig. 1): Phase A Stakeholder Mapping, Phase B Participatory Decision Support Workshop Implementation, and Phase C Action Plan Development.

Phase A: Stakeholder mapping

Phase A is the mapping of stakeholders within the Cypriot shipping industry value chain. The approach used was similar to the Prospex-CQI method (Gramberger et al. 2015) in that criteria (C) meaning the main categories of stakeholders that affect the topic of research (in this case shipping waste management) or are affected by it were defined, minimum Quotas (Q) for these categories were set, and Individuals were identified (I) that fall within the categories and fulfil the required quota. The mapping resulted in seven stakeholder categories:

- Government/Regulators: government bodies responsible for regulating the operation of ports and activities by the shipping industry. Three main bodies have these

responsibilities in Cyprus, and all were considered important for identification (Quota = 3). The Shipping Deputy Ministry is responsible for the overall supervision and regulation of the shipping sector, the development and coordination of the national shipping strategy, the updating and implementation of shipping legislation, the development of incentives, the promotion of maritime training and education, and the implementation of relevant studies and collation of statistical data. The Cyprus Port Authority is the public management body for all ports and harbours in the Republic of Cyprus. It is responsible for issuing licenses for the operation of companies and implementation of activities within portal areas, while also providing other key services such as waste management. The Department of Environment of the Ministry of Agriculture, Rural Development and Environment is the state's main environmental authority and has overall responsibility regarding the implementation of European and national environmental legislation, including on waste minimization and waste management. It is also the body responsible for licensing waste management companies.

- Chambers, Unions and Associations: in response to the large number of companies operating within the Cypriot shipping sector several chambers, unions and associations have been formed to represent the industry and promote its interests both nationally and internationally. For the stakeholder identification, the quota was set at seven to ensure all the major organizations were recorded through the stakeholder mapping. The most important of these is the Cyprus Shipping Chamber, representing over 200 companies on the island. Other important associations include the Cyprus Union of Shipowners, the Cyprus Shipping Association, the Cyprus Ship Suppliers Association, WISTA Cyprus, Nautical Institute Cyprus, and the Institute of Chartered Shipbrokers (Cyprus Branch).
- Port Terminals: this group includes all privately operated port terminals in the Republic of Cyprus. The quota was set at three to capture the three most important ones: DP World, a multi-purpose cargo and passenger terminal located within Limassol Port, Eurogate LCC port facility, a container terminal within Limassol Port, and VTS Vassiliko Terminal Services located in the area of Zygi.
- Ship Owners, Charterers, Operators: this category includes the 50 or so companies that either own, manage, charter or operate vessels flying the Cypriot flag. The quota was set at 10 companies, to capture the largest/most important ones.
- Suppliers and Business Partners: includes companies that offer services to ship managers. This can include, inter alia, catering services, ship maintenance services, logistical services, and environmental consultancy services. The quota was set at 5 companies.
- NGOs, civil society organisations and groups: focusing specifically on organizations based in Cyprus that work with the shipping industry and/or on the protection and preservation of the marine environment. The quota was set at 5 to capture the five most important organizations on the island.
- Research Institutes, Academia, Training: this category includes public and private research, education and training institutions that offer courses relevant to the shipping industry. The quota for the stakeholder mapping was set at 8.

The mapping was followed by the identification of stakeholders. A comprehensive stakeholder list meeting or exceeding the quotas stated above was developed in Year 1 and updated in Year 2 of the implementation of the DeCyDe-4-Shipping method. The following criteria were used to identify individuals within the seven stakeholder categories:

- Individuals with sufficient knowledge in the waste minimization and waste management operations of their organization, such as environment officers, directors of sustainability, general managers, etc.
- Individuals with a decision-making role in their organization (middle of upper management).

Ensuring identified stakeholders met these two criteria was important for the subsequent phases of the DeCyDe-4-Shipping method. Stakeholders had to have sufficient knowledge of what their organization is currently doing, but also what their organization's strategic vision with regards to sustainability, and particularly waste management, is to be able to effectively contribute to the discussion and the identification of gaps/needs that they are facing. At the same time, stakeholders had to be senior enough to be able to commit to the agreed actions/decisions taken during the workshop.

Phase B: Participatory decision support workshop implementation

Phase B concerns the design and implementation of the participatory stakeholder workshop. In Year 1, twenty-four stakeholders representing organizations from all seven stakeholder categories participated at the workshop. The workshop began with a collective intelligence exercise where stakeholders were engaged in the identification of the main gaps and needs that the Cypriot shipping industry is facing regarding waste minimization and waste management optimisation. Working in groups, the stakeholders identified the most important gaps and needs according to their perceptions and experience. Each group was comprised of a mixture of stakeholders, although it was not always possible to ensure representation of all the stakeholder categories in each working group. This was not a critical issue however, as the emphasis of this work was on encouraging discussion and identifying as many gaps and needs as possible. The outcome was a list of fourteen gaps/needs, which at this stage were considered equal in terms of weight and importance. Stakeholders were then given three coloured stickers each and asked to vote for the gaps/needs that they considered most important. Participants were free to distribute their votes as they wished, by assigning one vote to three different needs or multiple votes to one need. At the end of this collective intelligence exercise there was a ranked list of gaps and needs, based on stakeholder votes.

The five top-ranking gaps/needs were then selected and participating stakeholders worked towards the identification of solutions to meet these needs. Participants were split in five groups, each working on one need. Participants were free to participate in the group working on the need that was more relevant to their organization. Three solutions were identified for each gap/need. The identified solutions were then evaluated through the DeCyDe-4 multi criteria tool, by comparing couples as described in Loizidou et al. (2021) and Schumacher et al. (2018). This tool allows the ranking of the

solutions by comparing each solution against all others in a pairwise manner in the format of a matrix. The comparison was done twice, once for each of the following two criteria, which had equal weights:

- Applicability: how applicable is the solution regarding the legal framework, technical and financial aspects.
- Effectiveness: how effective will the solution be to minimize waste production and/or optimize waste management.

This part of the workshop resulted in a ranked list of solutions, at the top of which were those that participants considered to be most effective and applicable. The last part of the workshop included a facilitated wrap up discussion on the results of the working groups and the voting process, to ensure that there was consensus and mutual understanding regarding the practices to be included in the Action Plan.

In Year 2, Phase B, the workshop, took place in October 2022 as a side event to the 9th Environment for Europe Ministerial Conference. The workshop included an evaluation of the progress in the implementation of the previous year's Action Plan. The 15 stakeholders that participated in the workshop were asked to record the waste minimization and waste management optimization practices that had been implemented by their organisations in response to the actions included in last year's Action Plan. Through a collective intelligence exercise, such as that implemented in Year 1, stakeholders then voted for the five top-ranking gas/needs and the solution for each gap/need that they considered should be the priority for the 2022–2023 Action Plan.

The Year 2 method was upgraded to include a short evaluation survey at the end of the workshop. This is an important tool to record the perceptions of the stakeholders/participants in the workshop regarding the method used for developing the Action Plan, their level of confidence regarding the implementation of the identified actions, and their views on which body should take the Action Plan forward. The results of the evaluation survey were used to improve the methodology and address more specifically the concerns of the stakeholders.

Phase C: Action plan development

The outcomes of discussion, coupled with the working group and voting results of the DeCyDe-4-Shipping participatory workshop leads to Phase C of the method, which concerned the development of the annual Action Plan for Waste Minimization and Waste Management Optimization in Shipping in Cyprus.

Results and discussion

The Year 1 workshop was implemented in Limassol, Cyprus in October 2021, whereas the Year 2 workshop took place in Nicosia, Cyprus in October 2022, as a side event to the 9th Environment for Europe Ministerial Conference.

Participating stakeholders

Thirty-nine stakeholders representing the main shipping stakeholder categories as described in the method section, including the Shipping Deputy Ministry of Cyprus

(SDM), the Cyprus Port Authority (CPA), the Cyprus Shipping Chamber, representatives of ship owners, operators and shipping industry suppliers, NGOs working on environmental issues that concern the shipping industry, and privately managed port terminals participated at the workshops.

Outputs from 2021, the first year of implementing DeCyDe-4-Shipping: the baseline study

The first year of implementation of the DeCyDe-4-Shipping method resulted in the identification of the industry's main gaps and needs regarding waste management, and the identification of solutions to address the main needs, which led to the development of the first ever waste minimization and waste management optimization action plan for the Cypriot shipping industry.

Industry gaps/needs and solutions

Fourteen gaps and needs for the Cypriot shipping industry were identified and ranked by the stakeholders during the 2021–2022 workshop, and three solutions were identified and ranked for each of the five top-ranking needs (Table 1). There were two gaps/needs that concerned port reception facilities. The most important need (gap/need #1) concerned better infrastructure and services at port reception facilities. This is a particularly contentious point that was discussed at length during the workshop. According to ship owners and managers, waste onboard is separated and stored according to MARPOL, however, when ships reach port, the waste is collected all together in large skips. The Cyprus Port Authority (CPA) maintains that vessel crew fail to properly sort their waste, resulting in mixed or contaminated waste that cannot be accepted by waste collection companies. As a result, the CPA obtained a waste handling license from the Cypriot Department of Environment, which allows it to collect all the ship waste in a skip and then properly sort it into the various categories. The shipping industry noted that there is no accountability or responsibility when it comes to waste management and delivery (gap/need #4), mainly stemming from a lack of proper monitoring. For example, it was noted that there is no record of the weights of different wastes that are collected from ships at Cypriot ports, therefore there is no detailed baseline upon which to compare the results of waste minimization efforts. There are also no fines for those who do not comply with the proper waste separation requirement. The issue of insufficient controls and repercussions for non-compliant vessels has been identified in other work in the Mediterranean (Kyramargiou and Vardopoulos 2019). As potential solutions to address these issues, stakeholders suggested that there must be better separation of waste at port reception facilities, proper implementation of legislation that allows for controls and checks on vessels, greater monitoring in terms of weights collected, and increased accountability through the imposition of fines for those who fail to comply with mandatory waste segregation requirements.

Additionally, the stakeholders proposed that means to incentivize waste minimization should be implemented. Currently, the CPA implements an indirect fee system, whereby various categories of vessels pay a fixed waste handling fee regardless of whether they have any waste to deliver or not. The industry stakeholders suggested that this should be complemented by a Pay As You Throw scheme to incentivize vessels to reduce their waste. Towards this goal, it was also suggested that a Deposit Refund System can be

Table 1 Cyprus Shipping industry gaps and needs, and identified solutions for the five top-ranking needs, during 2021 DeCyDe-4-Shipping implementation

Rank	Gaps/needs (ranked)	Identified solutions (ranked)
1	Better infrastructure and services are needed at port reception facilities	1. Better separation of waste at port reception facilities 2. Implement a combination of standardised fees and Pay As You Throw schemes to ensure that best performers are incentivised 3. Implement Deposit Refund Systems on board to incentivise individual crew members and passengers
2	Environmental Culture, Education and Capacity-building are required	1. Incentivise the nurturing of an environmental culture through e.g. trainings, supply chain management etc 2. Implement awareness raising campaigns and knowledge transfer activities to the public and key target audiences 3. Impose fines to polluters (until the culture shifts)
3	Technological solutions and alternative materials are required	1. Dissemination and transfer of best practices 2. Solution-oriented research and development 3. Incentives for the application of innovative technologies
4	Accountability and responsibility are lacking	1. More monitoring in terms of what is delivered to ports and dumped at sea (e.g. weighing of waste delivered) 2. Accountability of what is being delivered to port and how well it is separated (fines for those who do not comply) 3. Proper implementation of legislation
5	Greater synergies are required between land and sea operations and between countries	1. Ensure that there are the same waste streams on vessels and at shore (e.g. through colour coding) 2. Develop synergies between owners/managers and suppliers and crew educators 3. Develop formalised/structured synergies among those involved
Additional gaps/needs (ranked)		
6	Better supply chain management is required to minimise plastic onboard	
7	There is a lack of availability of alternative (more environmentally friendly) packaging that can make procurement greener	
8	Incentives are needed to encourage companies to optimise their waste management	
9	There is a need to redesign materials and processes to make them more efficient	
10	Quality of data, recording, and monitoring needs to be improved	
11	Garbage fees vary between ports and lower prices can be linked to ports with poorer environmental performance	
12	There is no correlation between the MARPOL waste categories and the categories in which reception facilities accept waste	
13	Effective implementation of existing legislation is needed	
14	Evaluation by clients is required	

implemented on board vessels to incentivize individual crew members (for commercial vessels) and passengers (for cruise vessels) to separately collect waste with greater recycling value.

Working on the further development of an environmental culture within the shipping industry, and sustainability education and capacity-building for key management personnel and crew members, was identified as the second most important need for

the Cypriot shipping industry. This concerned specifically educating about the potential impacts of the industry's improper waste management on the marine and coastal environment, but also building capacity on best practices that could be implemented across the supply chain to reduce resource consumption and thus minimize waste production. The first means through which this could be achieved was through the provision of incentives for participation at trainings, and for monetary/contractual incentives through, for example, supply chain management. However, stakeholders also noted that until there is a noticeable and adequate culture shift within the industry, more controls could be implemented, and fines could be issued to polluters. Importantly, industry stakeholders stated that there are two misconceptions in the public domain regarding the shipping industry. The first is that the industry is a main culprit of marine litter pollution. The second is more of a lack of awareness rather than a misconception and concerns the fact that most Cypriots, particularly youth, are unaware of the size and importance of shipping to the island's economy and of potential career opportunities within the industry. Therefore, they suggested that greater effort should be placed on the implementation of awareness-raising campaigns and knowledge transfer activities targeting the public and other key target audiences such as for example youth.

Ranking third in the list was the need for more technological solutions and alternative materials that will help the industry minimize its waste. To do so, best practices that work elsewhere should be examined, assessed, adapted and transferred to the Cypriot shipping industry. Recognizing that this might not be sufficient, solution-oriented research and development should be implemented to address any specificities of the Cypriot industry and Cypriot facilities in terms of scale, insularity and so on. It was also noted that it is important to ensure that incentives are in place for companies to adopt emerging innovative technologies.

The stakeholders recognized that greater synergies are required between land and sea operations at Cypriot ports, but also between countries, as shipping is a global industry (gap/need #5). This could be implemented through simple means where there is a cohesive way to separate waste streams on vessels and at shore, for example through a colour coding system.

Synergies should also be explored between ship owners/managers, suppliers and crew educators as this will allow a common understanding of how products are purchased and how waste is handled. Finally, the stakeholders suggested that synergies should be formalized as much as possible to allow effective and constant coordination between those involved.

The 2021–2022 action plan

Using the outputs from the first DeCyDe-4-Shipping decision making workshop, the authors developed the 2021–2022 Action Plan (Additional file 1: Table S1) to optimize waste management. The developed Action Plan includes actions split across four Pillars:

- Pillar A: Creating fit-for-purpose port reception facilities. This concerns practices to ensure that Cypriot port reception facilities support and incentivize the minimization of waste and the proper management of resulting waste.

- Pillar B: Policy implementation and enforcement, which concerns both the proper enforcement of existing legislation and the development of policy instruments (not necessarily laws) that will support the optimized waste management onboard.
- Pillar C: Research and Innovation for the identification and implementation of innovative solutions for waste minimization and waste management optimization.
- Pillar D: Environmental behaviour and awareness raising. This pillar includes actions that should be considered horizontal activities, implemented alongside all other actions in the Action Plan.

These four Pillars arose from the grouping of the practices and actions that were discussed at the workshop into wider categories. For each of the actions in the Action Plan there is a recommended implementation schedule identifying short-term (completed within 1 year), medium-term (completed between 1 and 3 years), or long-term (completed between 3 and 5 years) actions.

Outputs from the 2022 DeCyDe-4-Shipping implementation: progress monitoring and updated action plan

The second year of the DeCyDe-4-Shipping method implementation engaged stakeholders in the reporting of the practices that they implement within their organizations to advance the 2021–2022 action plan, and in the prioritization of the solutions for improving waste management in shipping. The DeCyDe-4-Shipping participatory decision support workshop included the monitoring of the 2021–2022 Action Plan and resulted in the development of the 2022–2023 Action Plan.

Practices implemented by the Cypriot shipping industry

The monitoring of the 2021–2022 Action Plan implementation was done across the four Pillars of the 2021–2022 Action Plan. The process is collective, the stakeholders themselves identify, record, report the practices they implement, either by sending them before the workshop to the facilitators or presenting them during the workshop. Thirty-five practices implemented by the Cypriot shipping industry to minimise waste production and optimise waste management were recorded (Table 2). Some of these practices are implemented in Cyprus whereas others, reported mainly by shipping management companies and logistics/supply provision companies, concern practices that are implemented on-board or at ports of call, and are thus more international in nature. The wide geographic coverage of the practices demonstrates the positive impact that waste management minimization and optimization practices implemented by the Cypriot shipping industry can have globally.

Five of the eight practices recorded under Pillar A are implemented in Cyprus. They are implemented either by the Cyprus Port Authority or by privately operated port terminals and concern mainly the identification of licensed waste handlers that can collect the waste delivered from vessels and the provision of a greater number of equipment, mainly skips and compactors, to be able to accommodate the collection of the delivered waste. The relevant legislative framework on the operation of ports includes an article that allows the Cyprus Port Authority to impose reduced fees to vessels that call at Cypriot ports if they can prove that they have implemented practices for the reduction

of their waste. This was recorded as an implemented industry action. However, as it emerged from the discussion among stakeholders, neither the law nor the CPA specify what type of proof would be acceptable, resulting in uncertainty among vessels, which in turn leads to the non-application of this particular article. The practices under Pillar A which are implemented abroad concern bilateral agreements of ship management or supply provision companies with specific ports or waste handlers to ensure that waste is separately collected and recycled, even at ports of call where such practices are not implemented as a standard.

The smallest number of practices was recorded under Pillar B on policy implementation and enforcement, where five practices implemented in Cyprus were recorded. Three of these practices concern improved monitoring of what is delivered at ports, one of which is implemented by a privately operated port terminal and the other two by consulting firms that support the shipping industry to improve its monitoring and reporting as part of their wider sustainability practices. Interestingly, no practices were recorded under action B2 "Impose fines to polluters". This could link back to the issue of lack of monitoring and enforcement of the legislation that was identified by the stakeholders during the first workshop, suggesting that this problem persists. The last two recorded practices under action B3 "Formalize synergies" concern work done by a consulting firm with the International Maritime Purchasing Association to develop the International Maritime Procurement

Table 2 Actions implemented by the Cypriot shipping industry to reduce waste production and improve waste management

Action category	Implemented actions
Pillar A: Creating fit-for-purpose port reception facilities	
A1. Define waste categories and identify suitable and authorised waste handlers	1. Identification of licensed companies, implementation of waste separation [CPA]. *Implemented in Cyprus* 2. Defining waste stream categories, storage methods, and licensed handlers [Privately operated port terminal] *Implemented in Cyprus*
A2. Develop necessary infrastructure and waste segregation schemes	1. More equipment (skips) is made available at ports, and compactors have been purchased [CPA] *Implemented in Cyprus* 2. Waste categorization and segregation and correct storage [Ship management company] *Implemented abroad* 3. Promote and help suppliers around the world to collect packaging materials from vessels [Logistics/supply provision company] *Implemented abroad*
A3. Revise fees to incentivise waste minimisation	1. Law includes provision for reduced fees to vessels that implement waste minimization measures. Implementation of the provisions of the Law pending [CPA] *Implemented in Cyprus* 2. Made agreements with collaborating suppliers in Singapore so that when they complete their deliveries to vessels, they also collect all recyclables within MARPOL categories A (plastics) and C (other dry recyclables) without any additional costs to the ships. These dry recyclables are then delivered by the supplier to recycling plants [Logistics/supply provision company] *Implemented abroad*
A4. Transform Cyprus ports into pioneering Circular Ports	1. Identify entities that can reuse "waste" such as euro pallets, wire ropes, tyres etc.[Privately operated port terminal] *Implemented in Cyprus*

Table 2 (continued)

Action category	Implemented actions
Pillar B: Policy implementation and enforcement	
B1. Improve monitoring	1. Record and analyse waste production to identify trends and effects from implementing policies [Privately operated port terminal] *Implemented in Cyprus*
	2. Corporate sustainability reporting helps collect consistent data to improve monitoring [Consulting firm] *Implemented in Cyprus*
	3. Environmental supply chain due diligence [Consulting firm] *Implemented in Cyprus*
B2. Impose fines to polluters	
B3. Formalize synergies	1. Implementation of participatory, annual workshops for the shipping industry to record progress and define annual action plans for waste management [Consulting firm and SDM] *Implemented in Cyprus*
	2. Working with the International Maritime Purchasing Association (IMPA) to develop the International Maritime Procurement Sustainability Standard to make sure the maritime industry's supply chain meets minimum ESG criteria [Consulting firm] *Implemented in Cyprus*
Pillar C: Research and innovation	
C1. Identify main technological research and development needs	
C2. Incentivise the application of innovative technologies	1. Provide public exposure for suppliers and clients that use innovative technologies through reports and social media contents [Logistics/supply provision company] *Implemented abroad*
C3. Finance solution-oriented Research and Development	1. Financing of research on microplastics through the company's corporate social responsibility [ship management company supporting local NGO] *Implemented in Cyprus*
C4. Waste minimization practices	1. Collaboration with manufacturers to reduce packaging of delivered goods [privately operated port terminal] *Implemented in Cyprus*
	2. All ships provided with reverse osmosis water systems that are regularly checked by onboard engineers and yearly maintained at shore. This is coupled with the provision of reusable, biodegradable bottles. [ship management company] *Implemented in Cyprus*
	3. Several ships equipped with water filtration systems to reduce plastic water bottles [ship management company] *Implemented in Cyprus*
	4. Researching the possibility of banning single use plastics on board vessels [ship management company] *Implemented in Cyprus*
Pillar D: Environmental behaviour and awareness raising	
D1. Awareness-raising for the public	1. Informative campaigns about the Cypriot shipping industry [SDM] *Implemented in Cyprus*
	2. Implementation of Adopt-a-Ship program with schools [NGO and Cyprus Shipping Chamber] *Implemented in Cyprus* 3. Participation in Adopt-a-Ship program with several vessels [ship management company] *Implemented in Cyprus*
	4. Provision of sustainability training and development of corporate social responsibility campaigns that build awareness. [Consulting firm] *Implemented in Cyprus*
	5. Awareness-raising through media on the issue of waste management in shipping, marine plastic pollution and solutions. [Consulting firm] *Implemented in Cyprus*

Table 2 (continued)

Action category	Implemented actions
D2. Education for crew and decision-makers	1. Approval of environmental awareness activities of maritime training establishments [SDM] *Implemented in Cyprus*
	2. Seminars for seafarers and shipping executives. [NGO] *Implemented in Cyprus*
	3. Informational material on environmental issues for vessels [NGO] *Implemented in Cyprus*
	4. Promotion of recycling through training videos and campaigns. [privately operated port terminal] *Implemented in Cyprus*
	5. Marine pollution and garbage segregation included as mandatory crew training topics [ship management company] *Implemented in Cyprus and abroad*
	6. Instruct and educate vessels on how to identify and segregate MARPOL A&C categories for recycling [Logistics/supply provision company] *Implemented in Cyprus and abroad*
	7. Marine litter and plastic pollution included as training for staff and crew [Logistics/supply provision company in collaboration with NGO] *Implemented in Cyprus and abroad*
	8. Publish pieces in company editorials and company ESE reports to track and improve progress as well as notify employees about sustainability action [Logistics/supply provision company] *Implemented in Cyprus and abroad*
	9. Briefing (pre-departure and onboard) of crew regarding correct waste management [ship management company] *Implemented in Cyprus and abroad*
	10. Open report on environmental accidents and near misses to raise awareness among crew [ship management company] *Implemented in Cyprus and abroad*
D4. Business reward scheme/awards	1. Cyprus Maritime Awards [SDM] *Implemented in Cyprus*

Sustainability Standard, and the implementation of the annual stakeholder workshops that are presented herein. Interestingly, both of these were initiated by the private sector, albeit the workshops are supported by the Shipping Deputy Ministry of Cyprus, a public authority.

No practices were recorded for action C1 "Identify the main technological research and development needs". This is not surprising considering that there is no initiative to record the technological needs of the industry, nor are there industry-specific calls from the Shipping Deputy Ministry or the Research and Innovation Foundation, the public research funding institution in Cyprus. One supply provision company stated that they provide public exposure for any of their clients that use innovative technologies to minimise their resource consumption as an incentive for others to do so (action C2) whereas a ship management company mentioned that they fund a local NGO to implement research work on microplastics as part of their corporate social responsibility activities (action C3). Four practices were recorded under action C4 "Waste minimisation practices", all of them implemented in Cyprus, or on Cypriot vessels, concerning the

provision of reverse osmosis systems to minimise single use plastic bottles, taking steps to minimise all single use plastics, and collaborating with manufacturers to reduce the packaging of their delivered goods. This last practice was reported by a privately operated port terminal, and specifically concerns the packaging of safety boots that they purchase in bulk for their staff. The port terminal asked their supplier to deliver the safety boots without their cardboard packaging to minimise resources and prevent waste production. The supplier, based in Europe, charged them an extra fee for this service. This example demonstrates how a wider shift in mindsets and business models is required across the supply chain, as currently those thinking "outside the box" are asked to pay the price for it.

The greatest number of practices was recorded under Pillar D "Environmental Behaviour and Awareness Raising". Five practices aiming to raise awareness for the public were recorded, implemented by the Shipping Deputy Ministry of Cyprus, the Cyprus Shipping Chamber, NGOs and private consulting firms working with the shipping industry. Eight practices were recorded under action D2 "Education for crew and decision-makers" and include training and awareness raising activities for crew and at-shore personnel, and for the public. The last practice in Pillar D regards the Cyprus Maritime Awards that are implemented by the Shipping Deputy Ministry of Cyprus as a means of awarding pro-environmental behaviour within the shipping industry.

The 2022–2023 action plan

The recording of already implemented practices provided the background against which the shipping industry could set its annual Action Plan for 2022–2023 (Table 3). Three priority actions were defined for creating fit-for-purpose port reception facilities (Pillar A). While the Cyprus Port Authority and privately managed port terminals already have lists of waste management companies that are licensed to collect and transport waste that comes to Cypriot ports, the industry believes that it is important to review this list and add stricter criteria leading to the selection of contractors that are able to utilize the waste that they collect in accordance with the principles of the circular economy. Developing the necessary infrastructure that will allow waste to be properly segregated and thus valorised was identified as a subsequent priority action (A2). To facilitate and incentivise waste minimization among vessels, the stakeholders considered that it is a matter of priority for the CPA to issue guidelines clarifying the documentation that vessels need to procure to benefit from the reduced fees provision of the law governing the operation of port authorities.

Other actions that would incentivize and support the waste minimization efforts of the Cypriot shipping industry were also decided. Specifically, in Pillar B, stakeholders prioritized the improvement in the monitoring of waste that vessels delivered so that information on the amounts per category of waste is available, thus setting a benchmark across which to base the monitoring of the success of waste minimization efforts. In Pillar C, stakeholders stated that incentives for the adoption of innovative technologies that can lead to waste minimization should be provided (Action C2), whereas from an institutional point of view stakeholders noted that the Shipping Deputy Ministry can include an award for waste minimisation in its annual Cyprus Maritime Awards (action D3).

Table 3 The 2022–2023 action plan for the optimisation of shipping waste management

Action	Description	Organizations involved
Pillar A: Creating fit-for-purpose port reception facilities		
A1. Define waste categories and identify suitable and authorised waste handlers	Emphasis on identifying licensed contractors that utilise the collected waste according to the principles of the circular economy	SDM, CPA, privately operated port terminals, Individual shipping companies
A2. Develop necessary infrastructure	Following on from measure A1 above, and if necessary, additional infrastructure must be developed to ensure that waste is properly segregated to facilitate its collection and valorisation	SDM, CPA, privately operated port terminals, individual shipping companies
A3. Revise fees to incentivise waste minimisation	Clarify the provisions of the law that allows reduced fees to vessels that implement waste minimization measures	SDM, CPA
A4. Transform Cyprus ports into pioneering Circular Ports		SDM, CPA, privately operated port terminals, expert consultants
Pillar B: Policy implementation and enforcement		
B1. Improve monitoring	Collect information on the amounts of waste produced by vessels reaching Cypriot ports and report this information separately in accordance with MARPOL categories	SDM, CPA, privately operated port terminals
B2. Impose fines to polluters	Implement thorough and effective controls and impose fines, where necessary, as a disincentive for non-compliance. Fines should be greater than waste disposal fees	SDM, CPA, privately operated port terminals
B3. Formalise synergies	Implement waste management optimization workshops annually to formalize synergies between stakeholders	SDM
Pillar C: Research and innovation		
C1. Identify main technological research and development needs	Through discussions with suppliers, educators, owners/managers the most important technological gaps and needs with regards to waste minimization and management should be identified and prioritized	SDM, CPA, privately operated port terminals, individual shipping companies, expert consultants, academia
C2. Incentivise the application of innovative technologies	Provision of incentives for the application of existing innovative best practices that can minimize onboard waste production (i.e. transfer of best practices). The incentives could be financial and/or of a promotional character (see measure D4) and could build on the Green Incentives for decarbonization that are given by the Deputy Ministry of Shipping	SDM, EU Structural Funds, Directorate General Growth, Ministry of Finance, Research and Innovation Foundation of Cyprus

Table 3 (continued)

Action	Description	Organizations involved
C3. Finance solution-oriented Research and Development	Finance R&D that can identify and test solutions that will be feasible and effective, and that can solve needs of the Cypriot shipping industry. To do so, a dedicated call for proposals could be issued through the Research and Innovation Foundation, for example	SDM, EU Structural Funds, Directorate General Growth, Ministry of Finance, Research and Innovation Foundation of Cyprus
Pillar D: Environmental behaviour and awareness raising		
D1. Awareness-raising for the public	Continuation of the implemented awareness-raising campaigns	SDM, CSC, NGOs, expert consultants, individual shipping companies
D2. Education for crew and decision-makers	Include topics of circular economy in shipping and supply chain management in the training for crew, and particularly decision-makers	Entire shipping industry
D3. Business reward scheme/awards	Include waste minimization and waste management optimization as a category at the Cyprus Maritime Awards	SDM

To address the need for identifying and testing new innovative technologies that would support the industry in its waste minimization efforts, the stakeholders prioritized the provision of opportunities for the financing of R&D activities and pilot applications through several funding mechanisms, including the Research and Innovation Foundation of Cyprus, the Ministry of Finance of Cyprus, and the European Structural Funds. Resilience and Recovery Funds could also be used towards this direction as the research would support the transition to a green and circular economy. The concept of the circular economy (CE) and how it relates to the shipping industry was discussed at length during the workshop, as the industry recorded a self-perceived gap on this topic. Indeed, there is a scarcity of research work on applying the CE model in the shipping industry. This is because the CE is a place-based model in most cases, delimited and limited by the capacities and resources of the business ecosystem it is being developed in. Research work, for example, refers to circular ports or circular city-ports (de Langen, et al. 2020; Mańkowska et al. 2020; Roberts et al. 2021). Similarly, in this workshop, the port was considered the central point around which the CE system would be developed. This is not to say that port authorities were considered solely responsible for establishing a CE ecosystem. Stakeholder collaboration is very important, as industrial symbiosis needs to be developed both within the port and between the port and the surrounding territory for a truly circular model to be established (Girard 2013).

For the purposes of this work, the circular economy was thought of within the boundaries of the definition used by the European Commission, i.e. a "system which maintains the value of products, materials and resources in the economy for as long as possible, and minimises the generation of waste. This means a system where products are reused, repaired, remanufactured or recycled." (EUR-Lex 2023). This was a fitting definition for a workshop focusing on waste minimization and the optimization in the management of a variety of solid wastes produced and arriving at ports.

It was evident to the stakeholders that significant work must be implemented to transform Cypriot ports into circular ports, and while this is not something that can be achieved in a year, the stakeholders maintained that this should remain a part of the Action Plan as steps must begin to be taken in this direction. One of the first steps is including the circular economy and how it relates to shipping and how the supply chain can be managed to incorporate circularity principles, as training topics for crew and shipping industry decision-makers since these concepts are not particularly clear.

The practices included in the 2022–2023 Action Plan were grouped into four Pillars. Information in literature regarding waste minimization and waste management optimization in the shipping industry is particularly scarce, and it was not possible to identify similar Action Plans with which to compare the one developed in this work. Notably, however, Pillars B, C and D of the developed Action Plan reflect what Brynolf et al. (2016) have called the "three pillars for a greener maritime industry", being technological advancement, regulations and increasing awareness.

Stakeholder perceptions on the method, the action plan and the way to take it forward

The short evaluation survey that was shared with stakeholders at the end of the Year 2 workshop provided interesting insights into the perception of the Cypriot shipping industry stakeholders. The responses (n = 11) demonstrate that stakeholders need more

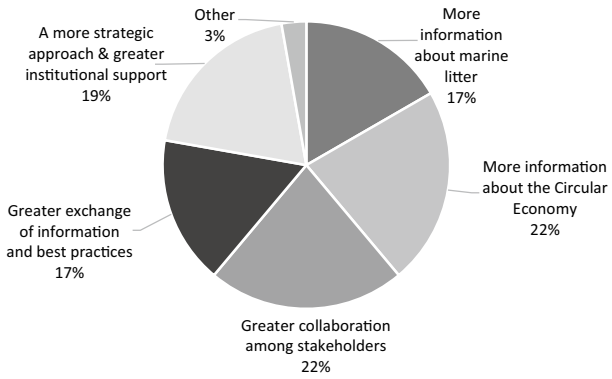

Fig. 2 The most important needs of the shipping industry regarding waste management optimization and plastic waste minimization

information about the issues of marine litter and the circular economy, and believe that the shipping industry could almost equally benefit from greater collaboration among the various stakeholders, greater exchange of information and best practices, a more strategic approach and greater institutional support (Fig. 2).

The workshop inspired the stakeholders to implement additional practices within their organizations for the reduction of plastic waste and the optimization of waste management (Fig. 3). This suggests that the implementation of such participatory methods can provide the means through which to address part of the Cypriot shipping industry's most important needs.

There is willingness among the respondents to join annual workshops to record the shipping industry's progress and to set priorities by updating the annual action plan for waste minimization and waste management optimization. Importantly, stakeholders were relatively confident that the practices identified in the Action Plan would be implemented, and that this effort should be led by a core group of industry representatives, while also recognizing the role of the Deputy Ministry of Shipping (Fig. 4). This finding

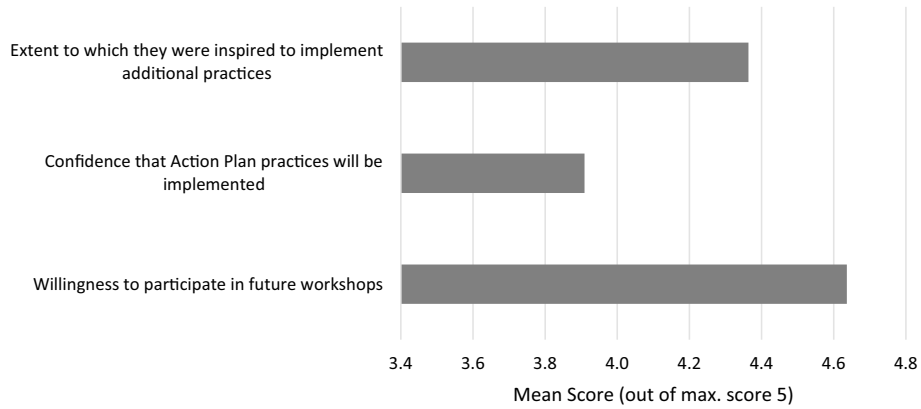

Fig. 3 Mean scores of participant's responses regarding given statements

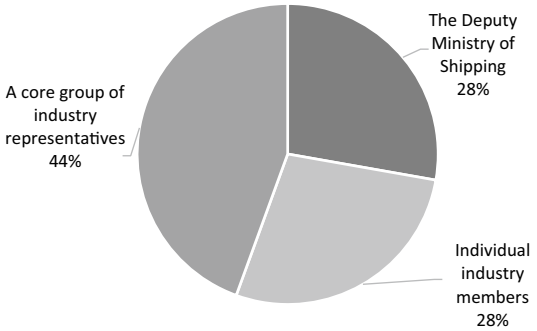

Fig. 4 Respondents' views on who should lead on the implementation of the action plan

suggests that the participating stakeholders understand that collective work is required to progress the Action Plan, and that there is interest and willingness among the Cypriot shipping industry to collaborate and work towards reducing their impact on the environment by minimizing plastic waste and optimizing the management of their waste.

Conclusions

Shipping is of vital importance to the economy of Cyprus, not only because of its contribution to the island nation's gross domestic product, but also because Cyprus depends almost exclusively on the shipping industry for trade. The Cyprus Shipping Strategy, issued by the Cyprus Shipping Deputy Ministry, aims for "Cyprus to be a significant and influential actor leading positive change in global shipping and an attractive maritime centre striving for sustainable growth and excellence" (https://cyshippingstrategy.com). While decarbonization is rightfully a priority for the shipping industry, waste management should not be neglected as it is intrinsically linked with the good environmental status of the marine environment, resource efficiency, circularity and thus climate change. The industry must thus be incentivized to concurrently work on minimizing resource consumption and optimizing waste management, adjusting and adapting its supply and value chain so that it becomes more circular.

In this article we presented the method implemented for engaging the shipping industry in the identification of waste minimization practices and overall waste management optimization through a participatory method that allowed effective multi-stakeholder interactions that resulted in the identification of actions that are relevant, effective, implementable, and stem from stakeholder consensus, indicating a commitment for action by the industry. A yearly Action Plan with prioritized actions has been developed, and the bodies responsible for taking the actions forward have been identified.

The DeCyDe-4-Shipping method is designed as an annual tool for identifying and implementing actions and policies towards the minimisation of plastic waste and the improvement of waste management in the shipping industry and for monitoring progress. Its strong participatory character results in stakeholder commitment and consensus for implementing actions and solutions that are site-specific, recording the industry's progress and defining priorities for the following year. The method results

in solution-oriented Action Plans with specific timeframes for implementation that are based on the perceptions and views of stakeholders attending the workshops.

The first 2 years of implementation in Cyprus demonstrate that the method is effective and efficient. The results from Year 2 suggest that the industry is indeed willing to implement actions and solutions which stem from a strong participatory process with the industry being the major actor for suggestions and actions. Through the DeCyDe-4-Shipping method, the industry holds ownership of the Action Plan maximizing the possibility that actions will be taken forward, as it was recorded through the evaluation part of phase B.

The development of the Action Plans cannot guarantee their implementation. The responsibility for the implementation of the actions is beyond the scope of the method and lies exclusively with the involved stakeholders, and particularly competent authorities. To address this issue, the DeCyDe-4 method requires the participation of the implementing competent authorities in the decision-making workshops. In this way competent authorities have time to work with their stakeholders within the working groups, they become part of the identification of the needs of the industry, and they have ownership of common suggestions. During the implementation of DeCyDe-4-Shipping in Cyprus, the Cyprus Shipping Deputy Ministry and port authorities were actively involved in the participatory process and played an important role in the development of the Action Plan. To ensure tangible progress, the competent authorities must not only endorse the Action Plans, but also provide the leadership, support the implementation of the actions and monitor the results. Through the annual implementation of DeCyDe-4-Shipping method, the implementation of the action plan can be monitored, more actions can be identified and problems addressed in order to find solutions.

Moving forward, as already mentioned, the DeCyDe-4-Shipping method can facilitate annual monitoring of Action Plan progress, allowing for updates and the inclusion of additional actions to continually enhance the industry's waste management performance. The participatory workshops are quick and do not require more than a few hours of the time of decision makers, and this is a comparative advantage. We propose extending the application of DeCyDe-4-Shipping to Mediterranean ports and beyond, leveraging its success to drive global progress in waste minimization and management within the shipping industry. Furthermore, the method can be adapted to address other environmental priorities such as the circular economy and greenhouse gas emissions, contributing to sector-wide sustainability efforts and gradual environmental footprint reduction.

In conclusion, the DeCyDe-4-Shipping method represents a significant step towards fostering industry-wide commitment to waste management optimization. By empowering stakeholders and fostering collaboration, this approach has the potential to drive meaningful change and pave the way for a more sustainable future in the shipping industry.

Abbreviations

CPA	Cyprus Port Authority
CSC	Cyprus Shipping Chamber
ESPO	European Sea Ports Organization
EU	European Union

NGO	Non-Governmental Organization
MARPOL	Marine Pollution Convention of the International Maritime Organization
SDM	Shipping Deputy Ministry of the Republic of Cyprus

Supplementary Information

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Additional file 1: Table S1. The 2021-2022 Action Plan for the optimisation of shipping waste management.

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Author contributions
XIL and MIL contributed to the study conception and design. Material preparation, data collection and analysis were performed by XIL, MIL, DLO, and DP. XIL and DLO contributed to the preparation of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The data generated and analysed during the current study are available in the Zenodo repository, https://doi.org/10.5281/zenodo.8112189. All other data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Competing interests
The authors have no financial or non-financial interest to disclose.

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