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SOS-ZEROPOL2030

D5.5 Roadmap

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Executive Summary

The SOS-ZEROPOL2030 Roadmap (Deliverable D5.5) provides an operational implementation framework translating the Strategic Zero Pollution Framework into a structured, actionable pathway towards reducing pollution in European seas.

The Roadmap identifies the activities, measures, and actions required to achieve EU zero pollution objectives across four key pollutant groups: nutrients, hazardous substances, microplastics, and underwater noise. It defines implementation pathways that specify responsible stakeholders, time horizons (2030, 2035, 2040), governance scales, and enabling conditions for action.

Developed through a co-design process integrating scientific evidence, policy analysis, and stakeholder input, the Roadmap bridges the gap between strategic environmental objectives and operational implementation. Key evidence sources include integrated assessments, governance analyses, Living Labs, SWOT analyses, and stakeholder consultations conducted within the SOS-ZEROPOL2030 project.

The Roadmap is implemented as an interactive digital dashboard (https://soszeropol2030.eu/roadmap), enabling users to explore actions through multi-criteria filtering based on pollutant type, stakeholder category, objectives, and implementation timeframe. Each action is presented through a standardised action/measure card containing structured information on responsibilities, implementation conditions, costs, barriers, opportunities, and policy relevance.

The digital platform is supported by a structured dataset and complemented by annexed tables containing the full implementation detail. Together, these components ensure full traceability between strategic objectives, operational measures, and their digital representation.

The Roadmap functions both as a strategic planning framework and as an operational decision-support tool, supporting coordinated implementation of zero pollution measures across EU governance levels and sectors. It enhances transparency, usability, and accessibility of complex environmental policy pathways and supports evidence-based decision-making for the transition towards zero pollution in European seas.

1. Introduction

1.1. Background

The European Green Deal and the EU Zero Pollution Action Plan establish an ambitious policy agenda aimed at preventing and reducing pollution across environmental compartments while protecting human health and ecosystems. Achieving these objectives requires coordinated action across the source-to-sea continuum via the application of the source-to-sea approach (Box 1-1), which recognises the complexity of pollutant sources, characteristics, effects, and pathways, and supports targeted actions across land, freshwater, and marine systems.

Box 1-1. *The source-to-sea approach.*

Source-to-sea refers to a comprehensive management strategy that takes a holistic view of the sources of, and solutions to, the problem of pollution. A source-to-sea approach is essential to address the intricate web of interconnected ecosystems comprising marine, land, and freshwater resources. Recognising the inherent interlinkages and dependencies among these ecosystems, the source-to-sea approach promotes coordinated actions that consider upstream and downstream linkages, ensuring that interventions in one part of the system do not inadvertently cause harm elsewhere (Granit et al., 2017; Mathews and Stretz, 2019; Del Savio et al., 2026). Implementing the source-to-sea approach involves several key components, including integrated governance across different sectors and administrative levels, robust data and monitoring across the source-to-sea continuum, aligned policies to ensure consistency and effectiveness of management, active community engagement for solutions that are context-specific and equitable, and adaptive management that can be adjusted based on monitoring data and changing environmental conditions (Granit et al., 2017; Mathews and Stretz, 2019; Del Savio et al., 2026).

Within this context, the Source to Seas – Zero Pollution 2030 (SOS-ZEROPOL2030) project developed the Strategic Zero Pollution Framework (Deliverable D5.1), which defines a comprehensive strategic approach for reducing pollution in European seas (Boteler et al., 2026). The framework focuses on four priority pollutant groups that represent major pressures on marine ecosystems: nutrient inputs, hazardous substances, microplastics and underwater noise.

While the Strategic Zero Pollution Framework establishes the project's long-term vision and strategic objectives, achieving these ambitions requires clear implementation pathways that translate strategic priorities into coordinated actions involving multiple stakeholders and governance levels.

1.2. Purpose of the Roadmap

The SOS-ZEROPOL2030 Roadmap (Deliverable D5.5) has been developed as the operational implementation component of the Strategic Zero Pollution Framework. Its purpose is to translate strategic objectives into a structured sequence of implementation measures that support the transition towards zero pollution in European seas.

The Roadmap identifies the activities, measures and actions required to achieve each strategic objective, together with the stakeholders responsible for implementation, indicative implementation timelines, and the principal challenges, barriers and opportunities that may influence delivery. In doing so, it provides an implementation-oriented perspective that complements the strategic direction established in Deliverable D5.1.

Rather than functioning solely as a static report, the Roadmap has been developed as an interactive digital platform (https://soszeropol2030.eu/roadmap) that allows users to explore implementation pathways according to their specific roles, responsibilities and areas of interest. The platform is designed to facilitate implementation planning, improve transparency, and support coordinated decision-making across sectors and governance levels.

1.3. Scope of the Deliverable

This deliverable describes the conceptual basis, development methodology and overall structure of the SOS-ZEROPOL2030 Roadmap. It explains the stakeholder-centred approach adopted for organising implementation actions, the principles used to structure the Roadmap, and the digital architecture developed to support its dissemination and practical application.

The detailed implementation pathways, including objectives, targets, actions and supporting implementation information for each pollutant area, are presented through the accompanying digital Roadmap and reproduced in the annexes to this report. Together, these components provide both the strategic context and the operational detail necessary to support implementation of zero pollution actions beyond the lifetime of the project.

2. Conceptual Framework of the SOS-ZEROPOL2030 Roadmap

2.1. Rationale

Achieving zero pollution in European seas requires coordinated action by a diverse range of actors operating across multiple governance levels. While environmental policies typically define strategic objectives, successful implementation depends on translating these ambitions into clearly sequenced actions that identify responsibilities, implementation requirements and expected timeframes.

The SOS-ZEROPOL2030 Roadmap was therefore conceived as an implementation framework that bridges the gap between strategic policy objectives and practical action. Rather than presenting recommendations as a static list of measures, the Roadmap organises them into a structured implementation pathway that enables users to understand what needs to be done, who should act, when actions should be implemented, and how individual measures contribute to the overall transition towards zero pollution.

This implementation-oriented perspective recognises that environmental governance is inherently collaborative. Many actions require cooperation among public authorities, industry, research organisations and civil society, while implementation frequently depends upon enabling policies, technological development, financing mechanisms and stakeholder engagement. The Roadmap therefore seeks to capture these interdependencies in a transparent and accessible manner.

2.2. Stakeholder-Centred Approach

A defining characteristic of the SOS-ZEROPOL2030 Roadmap is its stakeholder-centred design. Instead of organising information exclusively around pollutant categories or policy instruments, the Roadmap enables users to explore implementation pathways according to their own institutional responsibilities and decision-making roles.

Five principal stakeholder groups are considered:

- Policymakers and decision-makers
- Industry and economic Actors
- Researchers and academia
- NGOs and Civil Society Organisations
- Infrastructure and service providers

These stakeholder groups represent the principal actors involved in developing, implementing, supporting and monitoring zero pollution measures. By explicitly identifying stakeholder responsibilities for each implementation action, the Roadmap strengthens accountability, facilitates coordination and improves understanding of the contributions required from different sectors.

The stakeholder-centred structure also improves usability by allowing different user groups to rapidly identify actions that fall within their respective areas of responsibility while maintaining visibility of the broader implementation landscape.

2.3. Linking Strategic Objectives to Implementation

The conceptual structure of the Roadmap follows a hierarchical implementation logic that translates long-term strategic ambitions into operational actions.

At the highest level, the Roadmap reflects the strategic objectives established in the Strategic Zero Pollution Framework. These objectives are subsequently translated into measurable targets and implementation milestones distributed across three planning horizons:

- short-term (2030)
- medium-term (2035)
- long-term (2040)

Each milestone is supported by one or more implementation actions that describe the operational measures required to achieve the intended outcomes. Every action is accompanied by implementation information that enables users to understand not only what should be implemented but also the practical conditions necessary for successful delivery.

This hierarchical structure establishes clear traceability from strategic objectives through to individual implementation measures, ensuring that every action contributes directly to the project's overall zero pollution ambitions.

2.4. Guiding Principles

The development of the Roadmap was guided by five complementary principles.

- Implementation-oriented. The Roadmap focuses on practical implementation rather than policy description, translating strategic objectives into operational measures.
- Stakeholder-centred. Responsibilities are explicitly assigned to the organisations and stakeholder groups responsible for initiating or supporting implementation.
- Time-structured. Actions are organised according to implementation horizons that recognise different levels of policy maturity, technological development and governance readiness.
- Transparent. Each action includes supporting implementation information, including barriers, opportunities, implementation costs, governance scale, policy context and monitoring considerations, allowing users to understand the assumptions underlying implementation.

- Adaptive. The Roadmap has been developed as a digital resource capable of evolving alongside scientific knowledge, technological innovation and future policy developments.

Together, these principles provide a coherent framework for supporting implementation while maintaining sufficient flexibility to accommodate future updates.

2.5. From Conceptual Framework to Digital Roadmap

The conceptual framework described above provides the foundation for the digital SOS-ZEROPOL2030 Roadmap. The digital platform translates the implementation logic into an interactive environment that enables users to navigate actions according to stakeholder group, pollutant category and implementation timeframe.

Rather than functioning solely as a repository of information, the digital Roadmap serves as an implementation support tool that facilitates knowledge exchange, improves accessibility and promotes coordinated action among stakeholders involved in reducing pollution from source to sea.

The methodology used to develop the Roadmap, including the process for identifying actions, defining implementation attributes and structuring the digital platform, is presented in the following chapter.

3. Methodology for Developing the SOS-ZEROPOL2030 Roadmap

3.1. Overview of the Roadmap Development Process

The SOS-ZEROPOL2030 Roadmap was developed through a structured methodological process designed to translate the strategic objectives defined in the Strategic Zero Pollution Framework (D5.1) into a coherent set of operational actions and implementation attributes.

The development process followed a multi-step workflow in which strategic objectives were progressively decomposed into pollutant-specific targets, implementation measures, and structured action-level data entries. This process resulted in a harmonised dataset covering four pollutant groups (nutrients, hazardous substances, microplastics, and underwater noise), each described through a consistent set of fields enabling comparison, navigation, and digital visualisation.

A key feature of the methodology is that the Roadmap was designed simultaneously as a policy implementation structure and a machine-readable dataset, enabling its integration into an interactive digital dashboard.

3.2. Evidence Base and Input Data Sources

The Roadmap was developed using a structured synthesis of multiple evidence streams generated within the SOS-ZEROPOL2030 project. These inputs were not treated as standalone references but were systematically integrated into the definition of roadmap fields and action attributes.

A central role was played by case study analyses on tyre wear particles (TWPs) (Vlachogianni et al., 2026a) and perfluoroalkyl and polyfluoroalkyl substances (PFAS) (Vlachogianni et al., 2026b), which provided empirical evidence on pollutant pathways, source dynamics, mitigation options, and governance constraints. These case studies directly informed:

- definition of intervention types (source, process, end-of-pipe, enabling control);
- specification of implementation barriers and enabling conditions;
- identification of relevant stakeholder responsibilities; and
- structuring of monitoring and policy maturity indicators.

In addition, the Roadmap structure was informed by a broader set of project-generated evidence sources, including:

- Governance analyses, providing insight into institutional and regulatory implementation conditions (Devriese et al., 2023; Van Leeuwen et al., 2023).
- Living Labs, which provided applied testing environments and iterative stakeholder feedback loops (Van Hulst et al., 2024a; Van Hulst et al., 2025; Kopke et al., 2026);

- SWOT analyses, identifying systemic constraints and opportunities for implementation (Van Hulst et al., 2025);
- Stakeholder surveys, capturing perceived feasibility, barriers, and priorities across actor groups (Vaupotič et al., 2024).

These sources were used to validate and refine action-level attributes rather than to define the conceptual structure of the Roadmap.

Overall, the Framework and Roadmap were developed through a co-design approach that integrates outputs from the SOS-ZEROPOL2030 project and aligns them with the objectives of the EU Zero Pollution Action Plan. Within this process, multi-stakeholder engagement is embedded as a functional component of evidence generation and validation (Fig. 3-1). Stakeholder inputs both inform and are informed by scientific and analytical, contributing directly to the definition of pollution reduction, prevention, mitigation, and monitoring measures. This iterative exchange ensures coherence between scientific evidence, stakeholder knowledge, and policy objectives under the Zero Pollution framework.

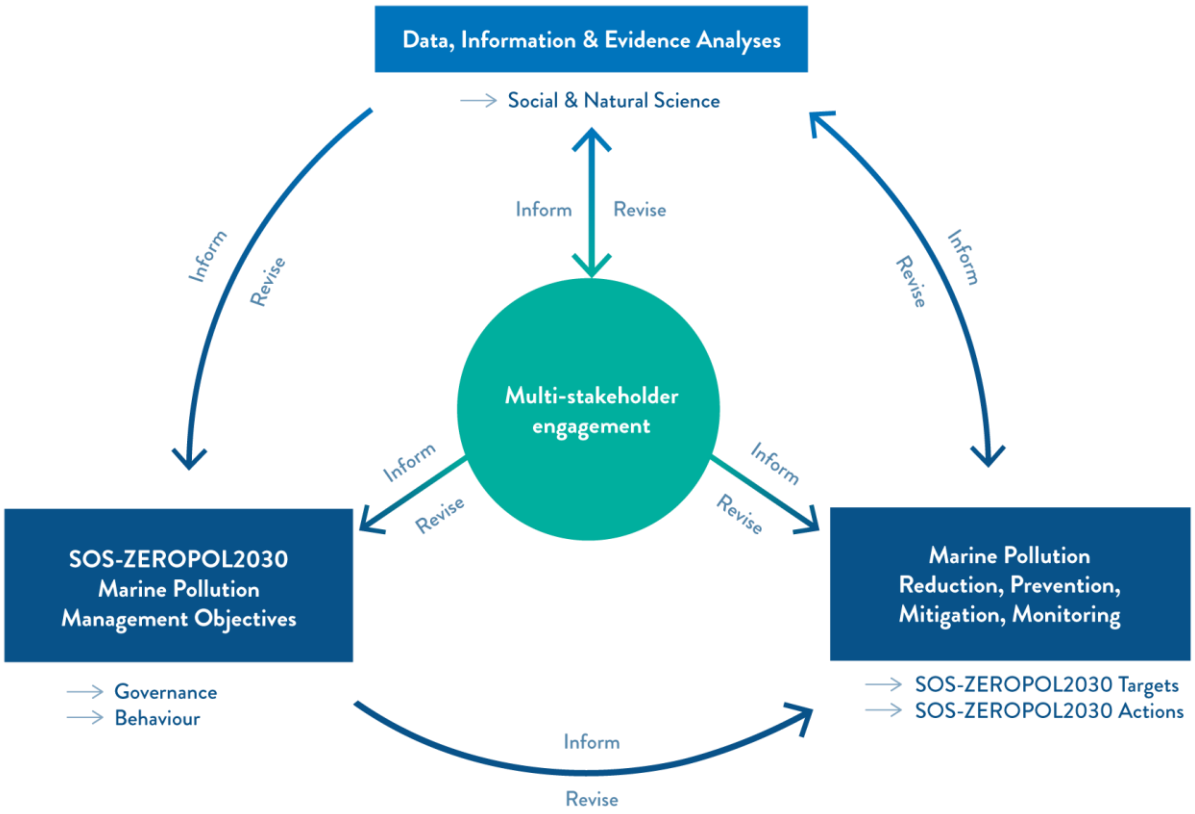

Figure 3-1. The Co-Design Approach of the SOS-ZEROPOL2030 Project.

3.3. Construction of the Roadmap Dataset

The Roadmap was operationalised as a structured dataset in which each action is defined through a harmonised set of fields. These fields were developed iteratively and refined through case study validation (TWPs and PFAS) and stakeholder input. Each action includes a standardised set of parameters:

- intervention description;
- pollutant category linkage;
- implementation timeframe (2030 / 2035 / 2040);
- responsible and supporting stakeholders;
- implementation scale (EU / national / local);
- implementation cost (low / medium / high);
- technology readiness level (TRL);
- policy framework linkages;
- Policy progress evaluation
- implementation barriers and enabling conditions;

This structure ensures comparability across pollutant groups and enables filtering and visualisation in the digital roadmap platform.

3.4. Action Typology Development

A key methodological step was the development of a harmonised intervention typology used across all pollutant groups. This classification was derived from both literature and case study evidence (particularly TWPs and PFAS) and refined through internal project validation.

Four intervention types were defined:

- Source control, addressing pollution prevention at the point of generation;
- Process control, reducing emissions during operational or production processes;
- End-of-pipe management, focusing on capture, treatment, or remediation after release;
- Enabling control, covering governance, monitoring systems, data infrastructures, modelling tools, and decision-support mechanisms.

This typology ensures consistent classification of actions and supports comparative analysis across pollutant domains.

3.5. Policy Progress and Technology Readiness Integration

Two cross-cutting analytical dimensions were integrated into the Roadmap dataset to support implementation assessment.

First, a policy progress evaluation scale (1–5) was applied to each action to indicate its maturity within the policy cycle, ranging from early conceptual development to full implementation and enforcement.

Second, Technology Readiness Levels (TRLs) were assigned where relevant to indicate the maturity of technological solutions supporting implementation.

These two dimensions were used to structure implementation feasibility assessments and to support prioritisation and sequencing of actions across time horizons.

3.6. Data Harmonisation and Quality Control

To ensure consistency across pollutant groups and evidence sources, all roadmap entries were standardised through a harmonisation process. This included:

- normalisation of stakeholder categories and roles
- standardisation of cost and scale classifications
- validation of intervention typology consistency
- cross-checking of action completeness against evidence inputs

This process ensured that all roadmap entries are interoperable within the digital platform and comparable across pollutant domains.

3.7. Methodological Output

The outcome of this methodology is a structured, multi-dimensional implementation dataset that forms the basis of the SOS-ZEROPOL2030 digital Roadmap.

The dataset enables:

- systematic navigation across pollutant groups, stakeholders, and time horizons;
- transparent linkage between strategic objectives and operational actions; and
- integration into an interactive digital dashboard environment.

The methodology therefore ensures that the Roadmap is not only policy-relevant but also technically structured for digital implementation and future updating.

3.8. Methodological Limitations and Interpretative Considerations

While the SOS-ZEROPOL2030 Roadmap is grounded in a structured evidence base and a harmonised methodological framework, several key parameters included in the dataset are based on expert judgement rather than fully quantitative outputs.

In particular, the following dimensions involve expert-based classification:

- implementation cost (low, medium, high);
- technology readiness level (TRL); and
- policy progress evaluation score (1–5).

These fields were derived through structured expert judgement informed by case study evidence on TWPs and PFAS, stakeholder input, and relevant literature. They should therefore be interpreted as indicative classification categories, intended to support comparative assessment, prioritisation, and discussion rather than precise economic or technological quantification.

It should also be highlighted that the measures included in the Roadmap within each target should not be interpreted as a sequential implementation plan. Rather, they represent complementary interventions operating across different stages of the source-to-sea continuum, which are expected to collectively contribute to the reduction of pollutant emissions and environmental exposure. Their effectiveness depends on coordinated and parallel implementation across governance levels and stakeholder groups, rather than adherence to a fixed order of execution.

Despite these limitations, the Roadmap provides a structured and coherent implementation framework that supports strategic alignment, stakeholder coordination, and evidence-informed policy development. It should therefore be interpreted as a decision-support and prioritisation tool under conditions of uncertainty, rather than a deterministic planning instrument.

4. Structure and Functionality of the Digital Roadmap

4.1. Overview of the Digital Implementation

The SOS-ZEROPOL2030 Roadmap is implemented as an interactive digital dashboard that operationalises the structured implementation dataset into a navigable and visual environment. The tool enables users to explore implementation actions, associated metadata, and temporal pathways across pollutant groups, governance levels, and stakeholder categories.

The digital Roadmap is accessible at: https://soszeropol2030.eu/roadmap

4.2. Technical Implementation and System Architecture

The digital Roadmap is developed as a web-based interactive application combining a structured backend dataset with a dynamic visualisation layer.

The system is built using Dash, a Python-based framework for interactive data applications. Dash was selected due to its capacity to support multi-criteria filtering, dynamic data interaction, and customised dashboard development.

The system architecture consists of:

- a structured roadmap dataset (backend database);
- an interactive visualisation layer; and
- a user interface enabling filtering and exploration of actions.

This architecture ensures full interoperability between the dataset structure (Annex) and the digital representation of actions.

4.3. Interface Structure and Visualisation Logic

The user interface is organised around a structured visual environment in which implementation actions are represented as interactive elements. Each action can be accessed through selection and is presented in a standardised format containing key implementation attributes. The interface supports both overview-level exploration and detailed examination of individual measures.

4.4. Software Environment and Development Approach

The digital Roadmap was developed using Dash, a Python-based framework for interactive web applications. Dash was selected over timeline-based tools (e.g. TimelineJS) due to its ability to support multi-criteria filtering, dynamic dataset interaction, and customised dashboard functionality.

Unlike timeline-only visualisation tools, Dash enables faceted navigation across multiple dimensions, including pollutant type, stakeholder group, objectives, and implementation timeframe. This flexibility was essential for implementing the Roadmap's multi-dimensional structure.

The platform also supports export functionality, allowing users to download filtered action/measure cards into PDF format for offline consultation and decision-support purposes.

4.5. Navigation and Filtering System

The Roadmap includes a multi-criteria filtering system that enables users to explore implementation actions according to key analytical dimensions. Users can filter actions based on:

- pollutant category (nutrients, hazardous substances, microplastics, underwater noise);
- stakeholder group (policymakers, industry actors, research organisations, NGOs/CSOs, infrastructure/service providers);
- implementation timeframe (2030, 2035, 2040); and
- objectives and targets under the Strategic Zero Pollution Framework.

The filtering system enables dynamic selection of relevant actions and supports targeted exploration of the implementation dataset.

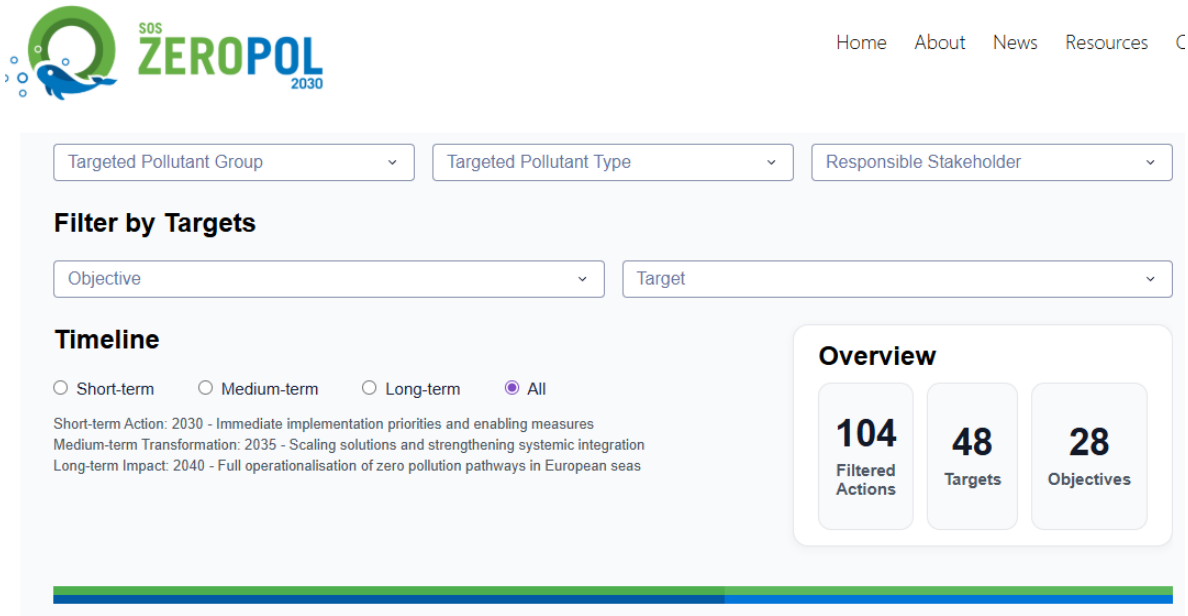

Figure 4-1. Filtering interface (pollutant and stakeholder selection).

4.6. Action Representation and Measure Cards

Each implementation measure in the Roadmap is represented as an interactive action/measure card within the digital dashboard. These cards constitute the primary unit of information within the system and provide structured access to all relevant implementation attributes.

Selecting an action/measure card opens a detailed view containing a standardised set of metadata fields, ensuring consistency across all entries in the Roadmap.

Each card includes the following information:

- description of the action/measure;
- associated objectives and targets under the Strategic Zero Pollution Framework;
- linked pollutant category;
- responsible stakeholders (lead and supporting actors);
- implementation timeframe;
- implementation scale (EU, national, local);
- indicative implementation cost;
- policy framework alignment;
- implementation barriers and opportunities;
- policy progress evaluation score (1–5); and
- technology readiness level (TRL).

This card-based structure enables users to systematically compare measures across different pollutants, governance levels, and implementation contexts. It also ensures that all actions are presented in a uniform format, supporting transparency and ease of navigation within the digital platform.

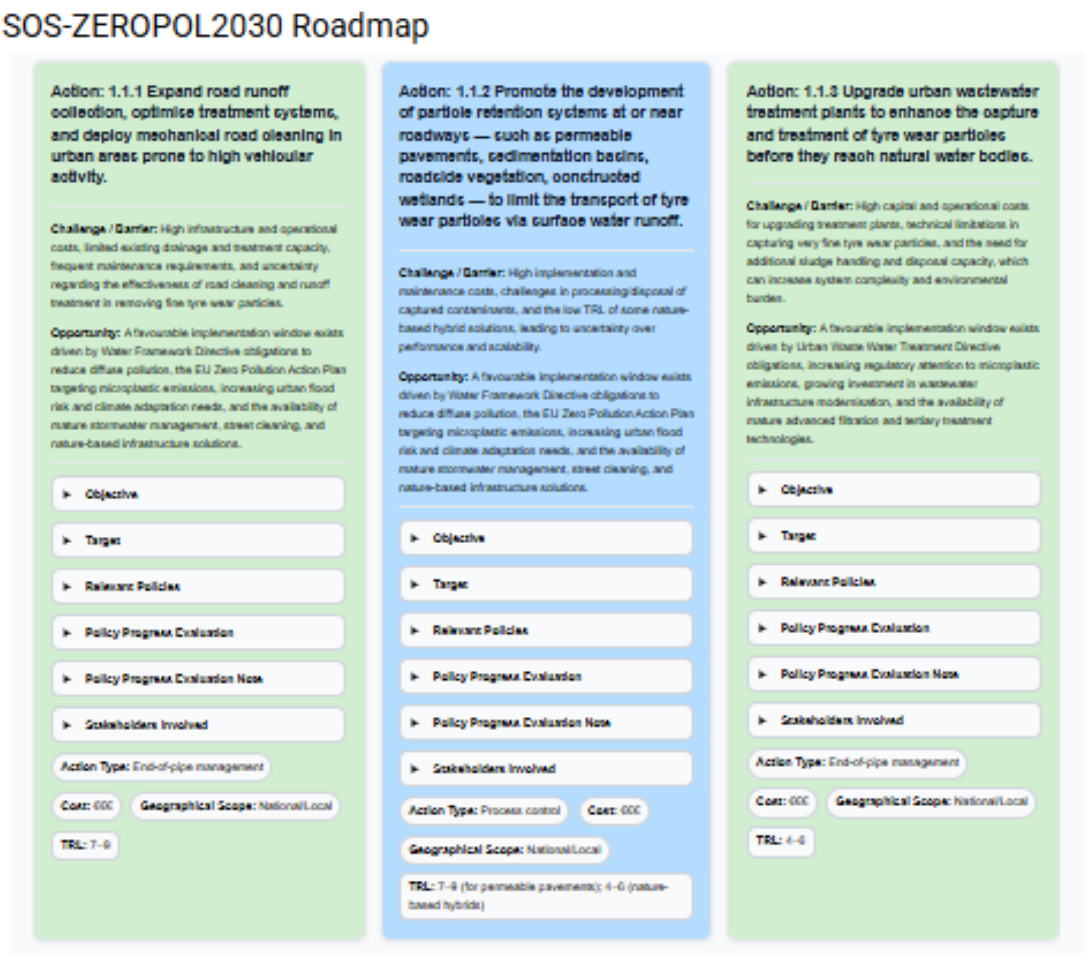

Figure 4-2. Example of an action/measure card in the SOS-ZEROPOL2030 Roadmap.

4.7. User Interaction and System Behavior

The digital Roadmap enables interactive exploration through filtering, selection, and navigation functions.

Based on selected filters, the system dynamically generates a subset of relevant action/measure cards, supporting targeted and context-specific exploration of implementation pathways. Users can refine or combine filters to adapt the level of detail and thematic focus of the displayed results.

The interface is designed to support non-linear exploration of the Roadmap content, facilitating flexible navigation across multiple analytical dimensions.

5. Roadmap Content and Implementation Pathways

5.1. Overview

The SOS-ZEROPOL2030 Roadmap translates the Strategic Zero Pollution Framework into four pollutant-specific implementation pathways covering nutrients, hazardous substances, microplastics, and underwater noise. Each pathway structures strategic objectives into operational targets and associated implementation actions, forming coherent transition trajectories towards reduced pollution pressures in European seas.

The detailed breakdown of objectives, targets, and actions is provided in the annexed tables.

5.2. Structure of Implementation Pathways

Each pollutant pathway follows a consistent logic linking strategic objectives to implementation measures through defined targets and operational actions. This structure ensures traceability between policy ambition and implementation while allowing adaptation to pollutant-specific characteristics and governance contexts.

Implementation measures are distributed across short-, medium-, and long-term horizons (2030, 2035, 2040), reflecting progressive scaling and system transformation rather than linear sequencing.

5.3. Pollutant-Specific Pathways

Nutrients: The nutrient pathway addresses eutrophication pressures through measures targeting agricultural nutrient losses, wastewater treatment optimisation, and catchment-based governance approaches. It combines regulatory instruments with management and monitoring measures across land–sea interfaces.

Hazardous substances: The hazardous substances pathway focuses on reducing chemical pollution through upstream prevention, substitution of hazardous compounds, regulatory controls, and improved monitoring systems. It reflects a lifecycle-oriented approach to chemical management.

Microplastics: The microplastics pathway addresses multiple sources of plastic emissions, combining upstream prevention, product and material design measures, and operational controls. Specific attention is given to tyre and road wear particles (TWPs), which represent a significant diffuse source of microplastic pollution.

Underwater noise: The underwater noise pathway includes measures targeting maritime transport, offshore activities, and coastal infrastructure. It integrates technical mitigation, operational practices, spatial planning, and monitoring approaches to reduce anthropogenic pressure on marine ecosystems.

5.4. Cross-Cutting Measures

Across all pollutant groups, the Roadmap includes cross-cutting actions supporting implementation coherence. These relate to governance coordination, monitoring and reporting systems, data infrastructure, technological innovation, and capacity building.

These measures enable integration across sectors and governance levels and strengthen the effectiveness of pollutant-specific interventions.

5.5. Link to Annexed Material

A detailed overview of objectives, targets, and actions for each pollutant pathway is provided in the annexes. These tables constitute the full operational breakdown of the Roadmap and should be read in conjunction with the strategic framework and digital implementation tool.

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Annexes

SOS ZEROPOL 2030