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D5.2 Tyre wear particles (TWPs) specific guidance to zero pollution in our seas

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Author(s): Thomais Vlachogianni, Andy Booth, Thomas Maes, Linda Del Savio, Lisa Devriese, Kathrin Kopke, Rian Ruhl, Judith Van Leeuven

Research Institute(s): MIO-ECSDE, SINTEF Ocean, GRIDA, RIFS, VLIZ, UCC, WR, WU

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Authors (alphabetical)	
Name	Organisation
Andy Booth	SINTEF Ocean
Linda Del Savio	Research Institute for Sustainability (RIFS) at GFZ
Lisa Devriese	Flanders Marine Institute (VLIZ)
Kathrin Kopke	University College Cork (UCC)
Thomas Maes	GRID-Arendal (GRIDA)
Rian Ruhl	Wageningen Research (WR)
Judith van Leeuwen	Wageningen University (WU)
Thomais Vlachogianni	Mediterranean Information Office for Environment, Culture and Sustainable Development (MIO-ECSDE)

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Executive Summary

Key messages

- Tyre wear particles (TWPs) are a major contributor to secondary microplastic pollution.
- Tyre wear chemicals (TWCs) and tyre wear leachates (TWLs) may present greater environmental risks than the particles themselves.
- Current policies address TWPs pollution only partially.
- Source reduction is the most effective long-term mitigation strategy.
- Coordinated cross-sector action is required.

TWPs are an increasingly important but often overlooked source of pollution in European aquatic environments. Generated continuously through vehicle use, TWPs consist of both particles and a complex mixture of associated chemicals (TWCs), many of which are toxic, persistent, and poorly understood. Due to their small size and mobility, TWPs are widely dispersed via road runoff, atmospheric transport, and wastewater systems, ultimately accumulating in freshwater and marine environments, where sediments act as long-term sinks.

The SOS-ZEROPOL2030 project identifies TWPs as a priority pollutant within the broader zero-pollution ambition for European seas. Scientific assessments highlight substantial knowledge gaps, particularly regarding environmental concentrations, transport pathways, and the toxicity of TWCs and their associated aqueous leachates (TWLs). While current estimates suggest relatively low concentrations of TWPs in open waters, uncertainties remain significant, especially concerning accumulation in sediments, long-term exposure, and combined effects with other pollutants.

Hotspot analysis indicates that emissions are strongly linked to traffic intensity, population density, and urbanization, with the Mediterranean Sea receiving the highest overall TWP inputs among European regional seas. Emissions are expected to increase due to ongoing socio-economic development, urban growth, and trends such as heavier vehicles.

Despite a broad EU regulatory framework addressing related aspects, TWPs are rarely addressed explicitly. Existing policies mainly act indirectly and exhibit gaps in monitoring, harmonization, and implementation. At the European Regional Seas level, there is currently no legislation explicitly targeting TWPs. At national level, no EU Member State has specific legislation directly targeting TWPs beyond existing EU-wide instruments. While several countries have incorporated TWPs into microplastic monitoring programs or research initiatives, these measures are primarily voluntary, advisory, or research based.

To achieve the Zero Pollution Vision 2030 target of reducing microplastics released into the environment by 30% by 2030, minimizing unintentional microplastic releases is key. Within this context, this guidance proposes a comprehensive source-to-sea framework of interventions structured around three levels: (i) source control that focuses on reducing

TWPs generation through improved tyre design, materials, and vehicle standards; (ii) process control that targets emissions during use through mobility strategies, infrastructure design, and driving behaviour; and (iii) end-of-pipe management that aims to capture and treat TWPs before they reach the marine environment.

Actionable recommendations include strengthening EU regulations (e.g. Euro 7, ESPR), integrating TWPs considerations into mobility policies, establishing harmonized monitoring and reporting systems, and promoting technological innovation such as particle capture systems and improved wastewater treatment.

Technological solutions range from readily deployable measures (e.g. improved road infrastructure, eco-design of tyres) to emerging innovations requiring further research, particularly in light of uncertainties related to vehicle types (e.g. electric vehicles vs internal combustion engine vehicles), tyre composition, and environmental behaviour of TWPs mixtures.

Importantly, addressing TWPs is not only a technical and regulatory challenge but also a societal one. Raising awareness, promoting behavioural change, and encouraging active societal engagement are essential to support effective implementation and long-term impact. At the same time, the successful deployment of mitigation measures will depend on a better understanding of their socio-economic implications, including implementation costs, technical feasibility, cost-effectiveness, and potential trade-offs across stakeholder groups. These aspects remain insufficiently quantified and represent an important area for future research and policy development.

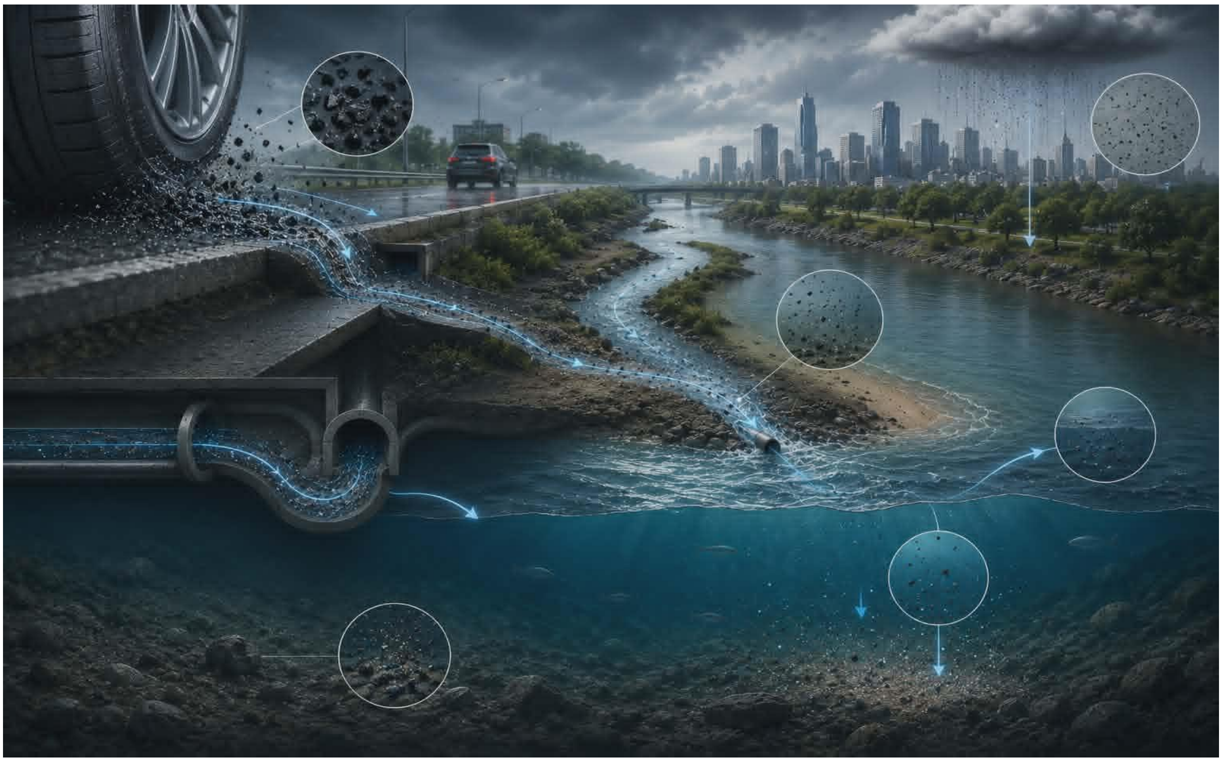

Figure 0-1. Conceptual illustration of TWPs pollution across the source-to-sea continuum.

1. Introduction

1.1. Purpose, Scope & Objectives

The Horizon Europe SOS-ZEROPOL2030 project aims to deliver a stakeholder-led European Seas zero-pollution framework to help achieve the European Union's long-term ambition of 'Zero Pollution' in European seas (https://soszeropol2030.eu). Central to the project is a source-to-sea approach (Box 1-1) to marine pollution, which recognises the complexity of pollutant sources, characteristics, effects, and pathways, and supports targeted actions across land, freshwater, and marine systems. In this context, TWPs were selected as a case study pollutant for microplastic pollution. Microplastics hereafter refer broadly to particles derived from plastics and other synthetic polymer materials in the size range <5 mm.

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).

This guidance translates the scientific and technical findings of SOS-ZEROPOL2030 into actionable recommendations for the prevention, reduction and mitigation of TWPs pollution in European seas. By providing clear, policy-relevant and practical guidance, this document aims to support policymakers, decision makers, and other stakeholders in implementing measures that reduce emissions at the source, mitigate environmental risks, and achieve measurable improvements in marine water quality.

The guidance sets out to:

- Synthesize knowledge on TWPs emissions, risks, governance and stakeholder insights gathered from the SOS-ZEROPOL2030 integrated assessments into practical guidance for action.
- Provide clear recommendations for policy and regulatory measures at European, national, and local levels to reduce TWPs input to seas.
- Identify TWP prevention, reduction and mitigation strategies and actions tailored to different sectors and stakeholders.
- Support informed decision-making, enabling policymakers and practitioners to prioritize interventions, allocate resources effectively, and monitor progress over a short term or medium-term horizon.
- Encourage coordination among relevant actors—including industry, research institutions, public authorities, and NGOs—to achieve comprehensive and sustained reductions in TWPs pollution.

1.2. Why TWP Pollution Matters

TWPs are a major and often overlooked source of microplastic and chemical pollution in aquatic environments (Maes et al., 2026). Generated continuously from everyday road use, they are widely dispersed and can be transported from roads into water bodies. TWPs persist in the environment and carry harmful substances (TWCs), posing risks to aquatic ecosystems and potentially to human health. To achieve the Zero Pollution Vision 2030 target of reducing microplastics released into the environment by 30% by 2030, minimizing TWPs releases is essential to reduce overall microplastic pollution and achieve cleaner, healthier European seas.

1.3. Target Audience

This guidance is intended for a wide range of stakeholders involved in reducing marine pollution from TWPs. These include:

- **Policymakers** – at European, national, and local levels, including those working within European regional sea conventions level, responsible for designing, implementing, and enforcing environmental policies.
- **Industry actors** – particularly tyre manufacturers, automotive companies, and transport operators, who can implement measures to reduce emissions at the source.
- **Researchers and academics** – providing scientific expertise, monitoring, and evaluation to inform evidence-based decisions.
- **Infrastructure and service providers** – including waste management, stormwater, and water treatment operators, who can help prevent TWPs and TWCs from reaching waterways.
- **NGOs and CSOs representatives** – supporting awareness, advocacy, and knowledge brokering for pollution reduction initiatives.

1.4. Methodology

This guidance is based on a combination of scientific analysis, expert input, and stakeholder knowledge. It draws primarily on the findings of the SOS-ZEROPOL2030 integrated assessments, which examine emissions, environmental risks, and management approaches for TWPs pollution (Booth et al., 2024). It also incorporates insights from Living Labs (Van Hulst et al., 2024; Van Hulst et al., 2025, Kopke et al., 2026), SWOT analyses (Van Hulst et al., 2025) and stakeholder surveys (Vaupotič et al., 2024), capturing perspectives on the challenges, risks, and potential solutions related to TWPs pollution. The broader lines of action included in this guidance are defined in the SOS-ZEROPOL2030 Framework (Boteler et al., 2026) and Roadmap (Vlachogianni et al., 2026).

1.5. Typology of Measures for Tackling TWP Pollution

Addressing TWPs pollution requires a comprehensive and integrated approach that combines policy and regulatory, technological, and social engagement measures. To support structured decision-making, this guidance adopts a three-tiered typology of interventions, based on where and how measures act along the pathway from emission to environmental impact.

This framework enables action across the entire life cycle of tyres—from design and use to runoff and particle capture—thereby supporting more effective and sustainable pollution reduction.

- **Source Control**: Measures that prevent or reduce the generation of TWPs at the source, including enhanced tyre design, the use of eco-friendly materials, and vehicle standards that minimize abrasion and particle release.
- **Process Control:** Measures that reduce TWPs emissions during operational processes while tyres are in use, such as road design and maintenance practices, optimized driving behaviours (eco-driving), reduced vehicle use, or improved traffic flow.
- **End-of-Pipe Management**: Measures that capture, treat, or mitigate TWPs after they have been released into the environment.

In addition, **enabling control measures** refer to cross-cutting tools and systems—such as monitoring, data collection, modelling, and information systems—that support, inform, and optimize interventions across source, process, and end-of-pipe control categories.

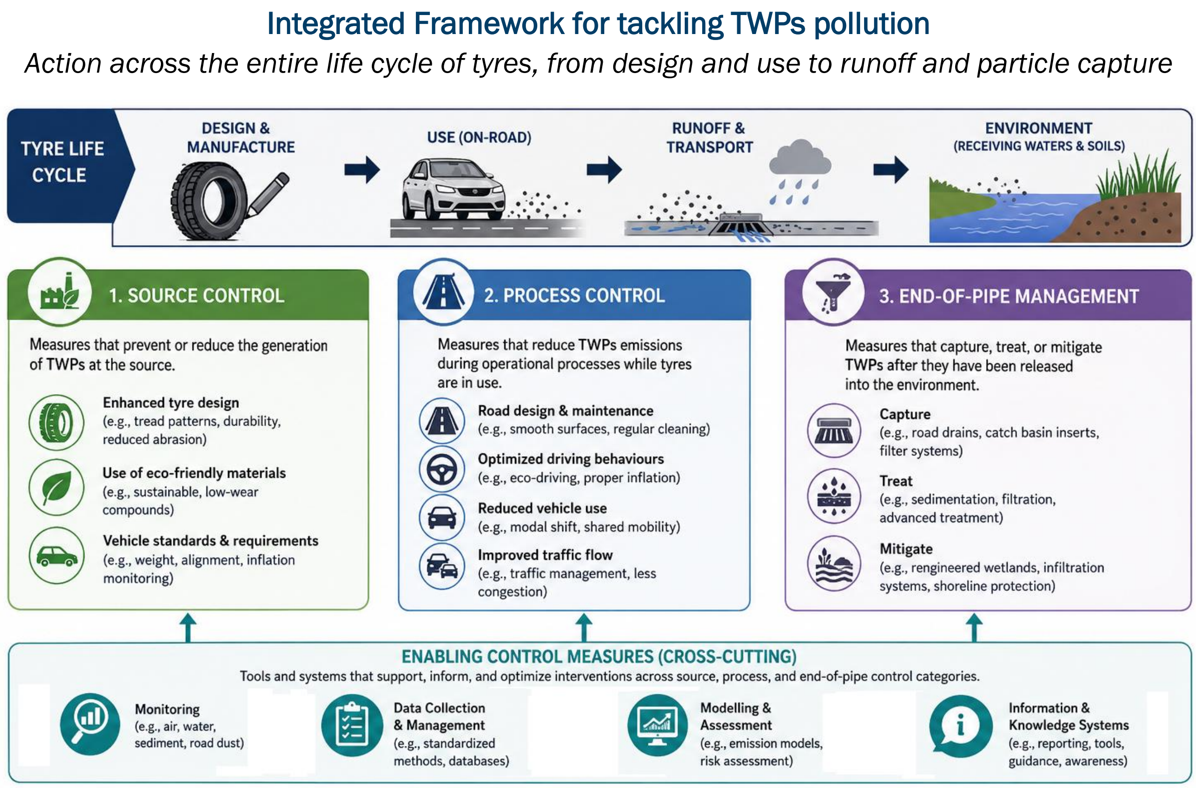

Figure 1-1. *A three-tiered typology of interventions for tackling TWPs: source control, process control, and end-of-pipe management.*

2. Understanding TWP Pollution

2.1. What Are Tyre Wear Particles and Tyre Wear Chemicals?

Tyres might keep us moving—but their invisible footprints are leaving a mark we can no longer ignore. Vehicle tyres are more than just rubber. In fact, natural rubber accounts for just 19% of a car tyre, with synthetic polymers accounting for 24%, fillers for 26% and additive chemicals 14%. Tyre design is optimized to deliver high performance in key areas such as safety, (wet)grip, rolling resistance, and noise reduction.

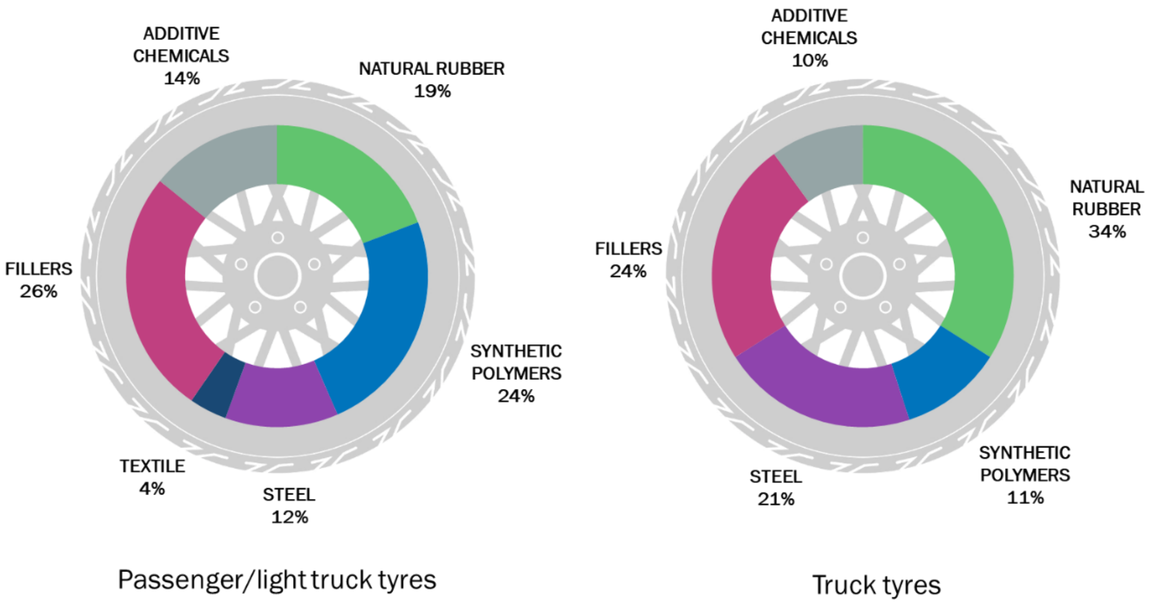

Figure 2-1. *Tyres composition (Adapted from U.S. Tire Manufacturers Association).*

TWPs are tiny fragments that are released from tyres as they wear down (Kovochich et al., 2021) and have been recognized as a significant source of microplastics, small plastic particles less than 5 mm in size, in at least two dimensions. The amount of TWPs released and their concentration in the environment are highly variable, both spatially and temporally (Booth et al., 2024).

It should be emphasized that TWPs represent two distinct forms of pollution: the elastomeric particles themselves and the associated chemicals, hereafter termed tyre wear chemicals (TWCs) (Maes et al., 2026). TWCs comprise the full suite of chemical additives and transformation products present in tyres or within TWPs, including both soluble and insoluble substances such as antioxidants and their degradation products; nearly 800 additives and non-intentionally added substances (NIAS) are known to be used or present in tyres and TWPs (Müller et al., 2022).

TWLs refer to the cocktail of native and transformed TWCs dissolved in natural waters following leaching from TWPs or tyre granulates under environmental conditions (e.g., rainfall, road runoff, or direct contact with aquatic systems). TWLs therefore represent a complex and variable mixture of dissolved organic and inorganic chemicals released from TWPs. Insoluble substances, while still classified as TWCs, are not considered part of TWLs unless they occur in dissolved or colloidal form. This distinction ensures that TWCs represent the total chemical inventory associated with tyre wear, while TWLs specifically describe the dissolved chemical cocktail generated under aquatic leaching conditions.

Figure 2-2. *TWPs generation.*

2.2. Sources, Pathways and Fate of TWPs

TWPs are primarily produced through the friction and wear of tyres during vehicle operation, meaning that urban, highway, and rural roads are the main sources of TWP emissions, with a direct link between increasing traffic volumes and higher emissions. Heavier vehicles emit more particles per distance travelled, while braking, accelerating, and turning further increase emissions. Emissions per kilometre are highest in urban areas due to frequent stop-and-go conditions, followed by highways and rural roads. Seasonal variations also influence emissions: summer tyres tend to release more TWPs, whereas winter tyres—especially studded ones—contribute more to road surface wear.

Over a typical lifespan of 40,000–50,000 km, tyres are estimated to lose 10–30% of their original mass as TWPs (Unice et al., 2012; Giechaskiel et al., 2024). With an average tyre mass of 8.2 kg for cars and 70 kg for trucks, this corresponds to approximately 1.2 kg and 12.6 kg of rubber emitted to the environment per tyre, respectively. TWP generation varies widely depending on tyre formulation, road type (Knight et al., 2020), and driving behaviour (Councell et al., 2004).

TWPs primarily enter the environment via direct road surface deposition, road runoff, atmospheric deposition, and wastewater treatment plant effluents (Eisentraut et al., 2018; Parker-Jurd et al., 2021). Once released, they can be transported by wind and water, accumulating in soils, freshwaters, and marine environments (Wagner et al., 2018). Smaller TWPs (<100 μm) and mobile TWCs leached from tyres or TWPs are prone to long-range transport, including into groundwater and other receiving waters (Järlskog et al., 2022; Vijayan et al., 2022). As with many pollutants, the marine environment likely serves as the ultimate sink for a large proportion of TWPs and TWCs, although surprisingly little is actually known about the true amounts. Due to their higher density relative to freshwater and seawater, TWPs tend to sink and accumulate in sediments. Evangeliou et al. (2020) estimated that approximately 35% of emitted TWPs ultimately deposit in the world's oceans.

2.3. Environmental and Human Health Impacts

Most research to date has focused on the toxicity of individual TWCs and their corresponding TWLs, rather than on the effects of TWPs themselves. In aquatic environments, TWPs are ingested by a wide range of organisms—from algae and zooplankton to fish—causing both physical and chemical impacts (Garrard et al., 2022; Wang et al., 2025).

Algae, forming the base of aquatic ecosystems, are highly sensitive to leachates containing metals and organic additives, with growth inhibition observed even at low concentrations (Capolupo et al., 2020). Copepods (*Tigriopus japonicus*) and daphnids (*Daphnia magna*) show acute effects primarily due to zinc and benzothiazole leaching (Yang et al., 2022; Marwood et al., 2011), while zebrafish (*Danio rerio*) exposed to micro- and nano-sized TWPs experience developmental defects, delayed hatching, and mortality. The chemical 6PPD-quinone has been identified as a particularly toxic transformation product of the common tyre additive 6PPD, exhibiting species-specific effects (Cunningham et al., 2022). Other aquatic organisms, including Mediterranean mussels (*Mytilus galloprovincialis*), amphipods (*Hyalella azteca*), macroalgae (*Ulva lactuca*), and fathead minnows (*Pimephales promelas*), similarly show adverse effects ranging from impaired growth and reproduction to mortality (Yoganandham et al., 2024). Across taxa, TWCs and their associated TWLs drive toxicity, while particles themselves can exacerbate these effects, highlighting mixture toxicity as a critical consideration (Piarulli et al., 2025).

Toxicity identification and evaluation of leachates indicate that zinc (Zn) is a key toxicant in the inorganic fraction, while a wide range of chemicals act as hazard-driving substances in the organic fraction. Variation in the toxicity of TWLs between different tyres has been demonstrated; however, there remains insufficient evidence to identify all of the specific chemicals responsible for the observed differences.

A meta-analysis of microplastic particles by Everaert et al. (2018) proposed a safe water concentration of 6,650 particles m^{-3}, below which adverse effects are considered unlikely in the marine environment, though this threshold is not specific to TWPs, for which current evidence suggests may exhibit higher toxicity than many conventional thermoplastic particles (Sørensen et al., 2023).

TWPs pose potential human health risks via inhalation and ingestion exposure pathways. Laboratory studies suggest that extracts from tyre tread can cause cytotoxicity, oxidative stress, inflammation, and endocrine or receptor-mediated effects, though findings are inconsistent and may not fully represent exposure to whole TWPs (Yoganandham et al., 2024). Airborne TWPs have been assessed for cardiopulmonary effects, with a human-equivalent No-Observable-Adverse-Effect-Concentration of 55 $\mu g/m^3$ indicating modest risk at typical environmental levels (Kreider et al., 2012). Nevertheless, important uncertainties remain, particularly regarding long-term exposure outcomes and the susceptibility of sensitive populations, including potential carcinogenic and reproductive effects, which are still poorly characterized. Current evidence remains insufficient for robust quantitative human health risk assessment.

3. Assessing the Problem

3.1. Key Findings from the SOS-ZEROPOL2030 TWP Risk Assessment

As part of the EU SOS-ZEROPOL2030 project, a scenario-based risk assessment framework was developed for complex pollutants and emerging contaminants, such as TWPs (Maes et al., 2026). The TWP risk assessment process integrated a detailed exposure assessment based on reported exposure concentrations and modelled data across different European regional seas with a hazard assessment based on database and literature toxicity data and modelling. Due to the complex nature of TWPs, the risk assessment was conducted separately for TWPs as particles and for the associated TWCs/TWLs. Three scenarios were developed, each reflecting varying levels of availability of empirical exposure and hazard data for a specific pollutant and indicating when modelled data need to be utilised. Each scenario also demonstrated how the reliability of the risk assessment decreases with an increasing reliance upon modelled data.

The assessment identified significant data gaps, particularly a lack of empirical concentration and exposure data for TWPs in marine environments. For TWCs and TWLs, available data remain insufficient for direct use in risk assessments, necessitating reliance on modelling approaches. The TWP risk assessment indicated that current particle emission concentrations in natural waters are unlikely to be above critical threshold values for microplastic particles, but this does not account for TWP accumulation in sediments, nor does it account for TWCs/TWLs, which are much more toxic.

TWLs comprise complex mixtures of TWCs that vary in composition and cannot be directly measured in environmental samples; only individual TWCs can be measured. Hazard assessment could be performed for only a limited number (~10) of TWCs. However, many TWCs originate from multiple sources, making it difficult to attribute individual TWC concentrations in environmental samples. As a result, they cannot be reliably used in risk assessments.

3.2. High-Risk Areas and Hotspots

Modelled riverine emissions of TWPs to European marine waters show that the highest-load catchment areas are predominantly in the North-East Atlantic region (Fig. 3-1a) (Booth et al., 2024; Maes et al., 2026). The riverine emission model estimated that between 82 million and 1.2 billion TWPs may enter each of the four European seas annually. However, several catchments in the Mediterranean and Black Sea regions contribute disproportionately to total European TWPs emissions. Consequently, the Mediterranean Sea receives the largest annual TWPs input among European regional seas, followed by the North-East Atlantic, Black Sea, and Baltic Sea.

Catchments delivering the highest TWPs concentrations are primarily in the Mediterranean basin, followed by the Black Sea, Baltic Sea, and North-East Atlantic, reflecting the influence of large population centres, sporadic rainfall, and relatively low river discharge volumes in southern and western Europe (Fig. 3-1b). Importantly, regions with lower and more sporadic rainfall can experience a build-up of TWPs in terrestrial matrices that are then washed into aquatic systems at high concentrations when precipitation events eventually occur.

Figure 3-1. *(a) The 20 river catchment areas discharging the highest annual total loads of TWPs within European Regional Seas. (b) The 20 river catchment areas discharging the highest annual TWP concentrations within European Regional Seas. For both maps, proportional circles show the total load of TWPs and TWPs concentrations per catchment area, respectively.*

Scenario-based modelling estimates mean TWPs concentrations in receiving waters ranging from 0.0001 to 0.016 particles m^{-3}, with actual concentrations varying seasonally across river catchments and regional seas. For risk assessment purposes, these modelled ranges are used as TWPs exposure concentrations at the points where catchments discharge into European regional seas.

3.3. Current Trends in TWPs Emissions

TWP emissions are closely linked to population density, traffic intensity, and urbanization, and are expected to increase in line with ongoing socio-economic development. The total load of TWPs in certain European seas, especially in closed basins, is extremely high. Annual emissions into European seas are estimated to range from tens of millions to over one trillion particles per year, depending on the scenario and modelling assumptions (Maes et al., 2026).

TWPs are continuously introduced into the environment via riverine transport, surface runoff, and wastewater pathways, making them a persistent and cumulative pollutant. Additional factors such as stormwater dynamics, urban drainage systems, and potential changes in climate patterns may further influence emission rates and transport pathways (Kang et al., 2025). Over time, due to the continuous accumulation of TWPs in regional seas, it is possible that chronic environmental and human health effects might occur, but further study is needed on this issue.

TWPs concentrations in the marine environment are likely to be highly localised around high traffic density areas close to the coast and at river mouths. Current estimates indicate relatively low concentrations of TWPs in open marine waters. However, these estimates do not account for accumulation in sediments, which may act as long-term sinks and secondary sources, nor do they consider the combined effects of TWPs with other microplastics (Booth et al., 2024).

Despite the scarcity of effect data, especially in relation to TWCs/TWLs, adverse ecological effects are expected to occur in the marine environment based on known toxicity assessments (Booth et al., 2024; Maes et al., 2026). Overall, TWPs represent a growing and largely unquantified environmental pressure.

3.4. Stakeholder Views: Understanding the TWPs Challenge

Key insights into the environmental challenges posed by TWPs were provided by wide ranging stakeholders in Living Labs organised within the framework of the SOS-ZEROPOL2030 project (Van Hulst et al., 2024; Van Hulst et al., 2025). These perspectives highlight critical knowledge gaps and practical concerns that complement the scientific findings of the SOS-ZEROPOL2030 risk assessment:

- **Persistence of TWPs in the Environment:** TWPs are highly durable and persistent in the environment, remaining in soil, water, and air for extended periods and accumulating in freshwater and marine sediments. Their small size and chemical composition have the potential for negative impacts in multiple ecosystems. Their persistence makes it difficult to mitigate long-term environmental damage once they are released into ecosystems.
- **Challenges in Understanding TWPs Transport Mechanisms:** Understanding how TWPs travel through different environmental media, such as air, water, and soil, is essential for predicting their spread and impact. However, the transport mechanisms of TWPs are still not well understood. These particles can be carried by wind, water runoff, or even through road dust, which complicates efforts to predict which environmental matrices will be most affected. The unpredictability of TWP distributions makes it difficult to assess the full scale of their environmental impact and to design effective mitigations and remediation strategies. Additionally, the interaction of TWPs with other pollutants in the environment may lead to synergistic effects that further exacerbate environmental harm.
- **Environmental Consequences of TWPs Mixtures:** The mixing of tyres from different manufacturers (with different chemical compositions) introduces additional environmental risks. When different tyre brands are used together, variations in chemical additives and materials may result in complex mixtures of TWPs that could have unpredictable environmental consequences. For instance, certain mixtures may contain higher levels of toxic compounds, including heavy metals or microplastics, which can leach into soil and water, posing greater risks to ecosystems.

4. The Policy and Regulatory Landscape

4.1. EU and European Regional Seas Level

The EU has established a range of regulations and directives that, directly or indirectly, address TWPs by targeting their sources, controlling associated emissions, and supporting monitoring and management of environmental impacts (Van Leeuwen et al., 2023; Van Hulst et al., 2024). These instruments (Table 4-1) operate across three main control types: source control, process control, and end-of-pipe/environmental management (Van Leeuwen et al., 2026; Del Savio et al., 2026). While some of these instrument's focus on reducing the quantity of TWP emissions, others are more relevant to addressing their toxicity.

The EU Zero Pollution Action Plan (European Commission, 2021) provides the overarching policy framework for long-term pollution reduction across air, water, and soil compartments. It sets the ambition of reducing pollution to levels no longer considered harmful to human health and ecosystems and explicitly includes the reduction of microplastics in the environment as a key target, establishing the Zero Pollution Vision 2030 target of reducing microplastics released into the environment by 30% by 2030. TWPs, as a significant source of microplastic pollution fall directly within this vision, particularly given their continuous release and transport through terrestrial and aquatic systems. At present, no EU directive or regulation explicitly and comprehensively governs "non-exhaust particulate emissions" as a unified category (including tyre wear, brake wear, road wear, and resuspension). This regulatory gap is being partially addressed by the Euro 7 Regulation, which represents the first EU legislative instrument to introduce specific requirements for selected non-exhaust sources, such as tyre abrasion.

Table 4-1. EU instruments addressing TWPs.

Instrument	Relevance	Type of Control	How it addresses TWPs
Euro 7 Regulation (Regulation (EU) 2024/1257)	Direct	Source control	Sets thresholds for abrasion limits from tyres (European Commission, 2022a)
Tyre Labelling Regulation (Regulation (EU) 2020/740)	Partial / Indirect	Source control	Requires tyre performance information, including safety and energy efficiency, to be reflected on labels when tyres are placed on the market (European Parliament and Council, 2020).

Instrument	Relevance	Type of Control	How it addresses TWPs
Ecodesign for Sustainable Products Regulation (ESPR) (Regulation (EU) 2024/1781)	Indirect	Source control	Sets minimum eco-design requirements, which will be applied to tyres under the ESPR first working plan (European Parliament and Council, 2024).
REACH (Regulation (EC) 1907/2006)	Indirect	Source control	Requires tyre manufacturers and importers to register products and provide information on substances used in tyre production (European Parliament and Council, 2006).
Industrial Emissions Directive (IED) (Directive 2010/75/EU)	Indirect	Process control	Establishes emission standards for the production of synthetic rubber used in tyre manufacturing (European Commission, 2010).
Urban Waste Water Treatment Directive (UWWTD) (Directive 91/271/EEC)	Indirect	End-of-pipe / Environmental management	Requires monitoring and treatment of wastewater and sludge, reducing TWP inputs to aquatic environments (European Commission, 2022b).
Water Framework Directive (WFD) (Directive 2000/60/EC)	Indirect	End-of-pipe / Environmental management	Establishes water quality monitoring and standards; TWPs may be captured under broader pollutant categories (European Parliament and Council, 2000).
Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC)	Indirect	End-of-pipe / Environmental management	Addresses marine litter and microplastics, providing a framework for monitoring and managing TWP pollution in marine environments (European Parliament and Council, 2008)

Beyond these binding regulatory instruments, recent EU policy developments further strengthen the strategic framework for marine pollution reduction. The European Ocean Pact (European Commission, 2025), published in 2025, places further emphasis on reducing pollution in the marine environment. It prioritises targeted action on nutrient, plastic, chemical, and noise pollution, while strengthening marine governance, monitoring, and international cooperation—key elements for restoring the health of Europe's seas and achieving good environmental status. A central principle of the Ocean Pact is the source-to-sea approach to pollution management, which guides policy action by explicitly considering land-based sources of marine pollution. In the context of TWPs, this framework is particularly relevant, as tyre wear particles are generated within land-based transport systems and subsequently transported via runoff and riverine pathways into marine environments, exemplifying the source-to-sea continuum addressed by the Pact.

At the European regional seas level, there is currently no legislation explicitly targeting TWPs. Existing frameworks address them only indirectly through broader microplastic monitoring and marine litter reduction initiatives. Under the Barcelona Convention, the Regional Plan for Marine Litter Management in the Mediterranean defines secondary microplastics to include rubber particles from tyre wear (Article 3) (UNEP/MAP, 2021). In contrast, under the Oslo-Paris Convention (OSPAR), both editions of the Regional Action Plan for Marine Litter do not explicitly reference tyre wear particles, which are instead considered within the broader category of microplastics (OSPAR Commission, 2014; OSPAR Commission, 2022). Similarly, the Black Sea Marine Litter Regional Action Plan under the Bucharest Convention does not specifically mention tyre wear particles (BSC, 2018), nor do the Helsinki Commission (HELCOM) action plans for the Baltic Sea (HELCOM, 2015; HELCOM, 2021). However, HELCOM has published a dedicated policy brief on TWPs, recognising them as a significant source of microplastics and outlining practical mitigation measures (HELCOM, 2022).

4.2. National Level

Currently, and to the best of our knowledge, no EU Member State has specific legislation directly targeting TWPs beyond the existing EU-wide instruments described under Section 4.1. While several countries have incorporated TWPs into microplastic monitoring programs or research initiatives, these measures are primarily voluntary, advisory, or research based.

5. The SOS-ZEROPOL2030 Transition Pathway for Reducing TWPs within the Zero Pollution Action Plan

5.1. Overview

Within the scope of SOS-ZEROPOL2030, a Strategic Zero Pollution Framework and associated Roadmap have been developed, defining objectives, targets, actions, and timeframes to support the achievement of the Zero Pollution Vision 2030 target on microplastics, including TWPs. The SOS-ZEROPOL2030 objective related to TWPs focuses on the minimisation of microplastic release from tyre and road wear into water bodies and is translated into three targets and nine actions, as shown in Table 5-1. Together, these elements operationalise the transition pathway for TWPs and underpin the sector-specific actionable guidance presented in the following sections.

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. Multi-stakeholder engagement is central to this process and is both informed by and contributes to data, evidence, and analytical outputs, as well as to the definition of pollution reduction, prevention, mitigation, and monitoring measures. This ensures coherence between scientific evidence, stakeholder input, and policy objectives under the Zero Pollution framework.

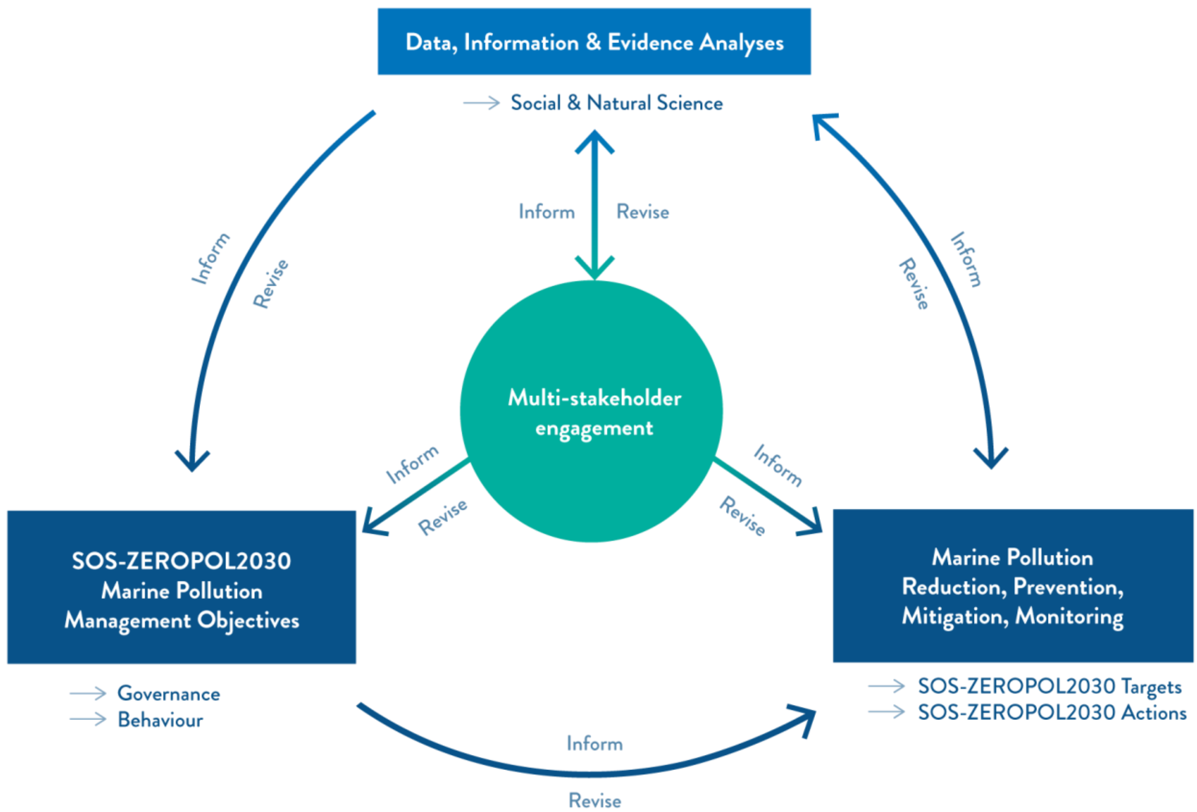

Figure 5-1. The Co-Design Approach of the SOS-ZEROPOL2030 Project

Table 5-1. The SOS-ZEROPOL2030 objective, targets and actions related to TWPs to support the Zero Pollution Vision 2030 Target on microplastics.

Target	Timeframe	Action
By year 2036, each Member State has implemented civil engineering solutions retaining or reducing the spread of tyre wear particles in at least 50% of its designated urban areas, prioritising regions with high traffic density and runoff impact.	medium-term	Expand road runoff collection, optimise treatment systems, and deploy mechanical road cleaning in urban areas prone to high vehicular activity.
	medium-term	Promote the development of particle retention systems at or near roadways – such as permeable pavements, sedimentation basins, roadside vegetation, constructed wetlands – to limit the transport of tyre wear particles via surface water runoff.
	medium-term	Upgrade urban wastewater treatment plants to enhance the capture and treatment of tyre wear particles before they reach natural water bodies.
	medium-term	Promote low-abrasion road surface materials and maintenance practices to reduce tyre wear particle generation.
By 2036, at least 40% of new vehicles and tyres placed on the EU market comply with enhanced eco-design standards aimed at reducing tyre wear particle emissions and improving overall environmental performance.	medium-term	Promote the design and mandatory labelling of low-abrasion tyres through EU eco-design requirements (including under the ESPR) and relevant product and vehicle legislation, including the Tyre Labelling Regulation and Euro 7 requirements where applicable.
	medium-term	Establish EU-wide performance criteria for tyre abrasion and rolling resistance, building on Euro 7 requirements and integrating them into vehicle eco-design requirements under the ESPR and vehicle type-approval frameworks to ensure consistency, enforcement, and continuous improvement in tyre environmental performance.
	medium-term	Support the development, testing, and adoption of on-vehicle tyre wear particle capture technologies through EU research and innovation programmes.
By 2030, Member States implement comprehensive policies promoting sustainable driving behaviour and reducing private car dependency in urban areas by at least 20% to lower tyre wear emissions and overall environmental impacts from road transport.	short-term	Develop and expand urban mobility policies that encourage modal shifts, such as improving public transit accessibility, investing in safe cycling and walking infrastructure, and establishing low-emission zones and expanding rail infrastructure to reduce reliance on private car use in urban centres.
	short-term	Mandate the inclusion of eco-driving modules in all new driver training and licensing programmes, complemented by public campaigns to low tyre-wear driving habits.

5.2. Limitations and scope considerations

It should be highlighted that the measures presented in this guidance should not be interpreted as a sequential implementation plan. Rather, they represent complementary interventions that operate across different stages of the source-to-sea continuum and are expected to collectively contribute to the reduction of TWPs emissions and environmental exposure. Their effectiveness depends on coordinated and parallel action across governance levels and stakeholder groups, rather than a fixed order of implementation.

In addition, the socio-economic dimension of the proposed measures is not quantified in this work. Information on implementation costs, technical feasibility, cost-effectiveness, and distributional impacts across stakeholders remains limited in the current evidence base, particularly for emerging technologies such as tyre wear capture systems and enhanced abrasion standards. While the costs of inaction may be significant in terms of environmental impacts and ecosystem degradation, such relationships remain insufficiently quantified across mitigation options. Cost–benefit relationships also remain uncertain across technologies and policy measures. This represents an important limitation for evidence-based prioritisation and highlights the need for further research to support robust decision-making and prioritisation of mitigation options within the Zero Pollution framework.

6. Policy and Regulatory Measures

6.1. Introduction

Despite existing EU policy and regulatory instruments, significant gaps remain in addressing TWPs at both the EU level and across European Regional Seas (Del Savio et al., 2026). Key challenges include limited explicit coverage of TWPs, incomplete or underdeveloped EU policies, lack of mandatory monitoring and reporting requirements, absence of harmonised standards, and insufficient integration of mobility and behavioural strategies.

Below, a set of policy- and regulatory-related recommendations is presented as actionable guidance for EU policymakers, though many of these measures are also relevant and useful for policy development at the European Regional Seas Conventions level (Van Hulst et al., 2024; Boteler et a;.2026; Kopke et al., 2026; Vlachogianni et al., 2026).

6.2. Actionable Guidance

Enhancing Tyre Design and Vehicle Standards

- Ensure effective implementation and progressive strengthening of tyre abrasion limits under Euro 7, including the development of robust monitoring, verification, and compliance mechanisms across Member States. (▲ Source Control)
- Further develop and harmonise performance standards for tyre abrasion, building on Euro 7 and integrating them into ESPR and vehicle type-approval frameworks to ensure consistency and long-term improvement in tyre environmental performance. (▲ Source Control)
- Expand the scope of the Tyre Labelling Regulation to include standardised and transparent information on tyre abrasion and TWPs emissions, enabling informed consumer choice and driving market uptake of low-emission tyres. (▲ Source Control)
- Accelerate the development and implementation of eco-design requirements for tyres under the ESPR, ensuring that durability, low abrasion, and reduced environmental impact are prioritised in upcoming delegated acts. (▲ Source Control)
- Promote innovation beyond current regulatory coverage, particularly by supporting the development and uptake of on-vehicle TWPs capture technologies through targeted funding and research programmes. (● End-of-Pipe Management)

Promoting Sustainable Mobility

Reducing overall TWPs emissions also requires systemic changes in mobility patterns, in line with the Sustainable and Smart Mobility Strategy:

- Strengthen and accelerate the implementation of sustainable urban mobility policies that promote modal shift, including investment in public transport, cycling and walking infrastructure, low-emission zones, and rail systems, to reduce reliance on private car use. (■ Process Control)
- Integrate TWPs considerations into existing mobility and transport policies, ensuring that tyre wear emissions are recognised alongside exhaust emissions in urban planning and transport strategies. (■ Process Control)

- Mandate the inclusion of eco-driving practices in driver training and licensing systems and support these measures with targeted public awareness campaigns promoting driving behaviours that reduce tyre wear. (■ Process Control).

Monitoring and Reporting of Tyre Wear Particles

- Integrate TWPs monitoring into existing environmental monitoring frameworks, including the UWWTD, WFD, and MSFD, to collect consistent data on TWPs concentrations in wastewater, freshwater, and marine environments. (◙ Enabling Control)
- Mandate reporting of TWPs emissions from road transport and urban runoff, using harmonised protocols to enable assessment of trends and effectiveness of mitigation measures. (◙ Enabling Control)
- Support the development of standardised indicators for TWPs contributions to microplastic pollution, to allow policymakers to link mitigation actions with improvements in environmental status. (◙ Enabling Control)

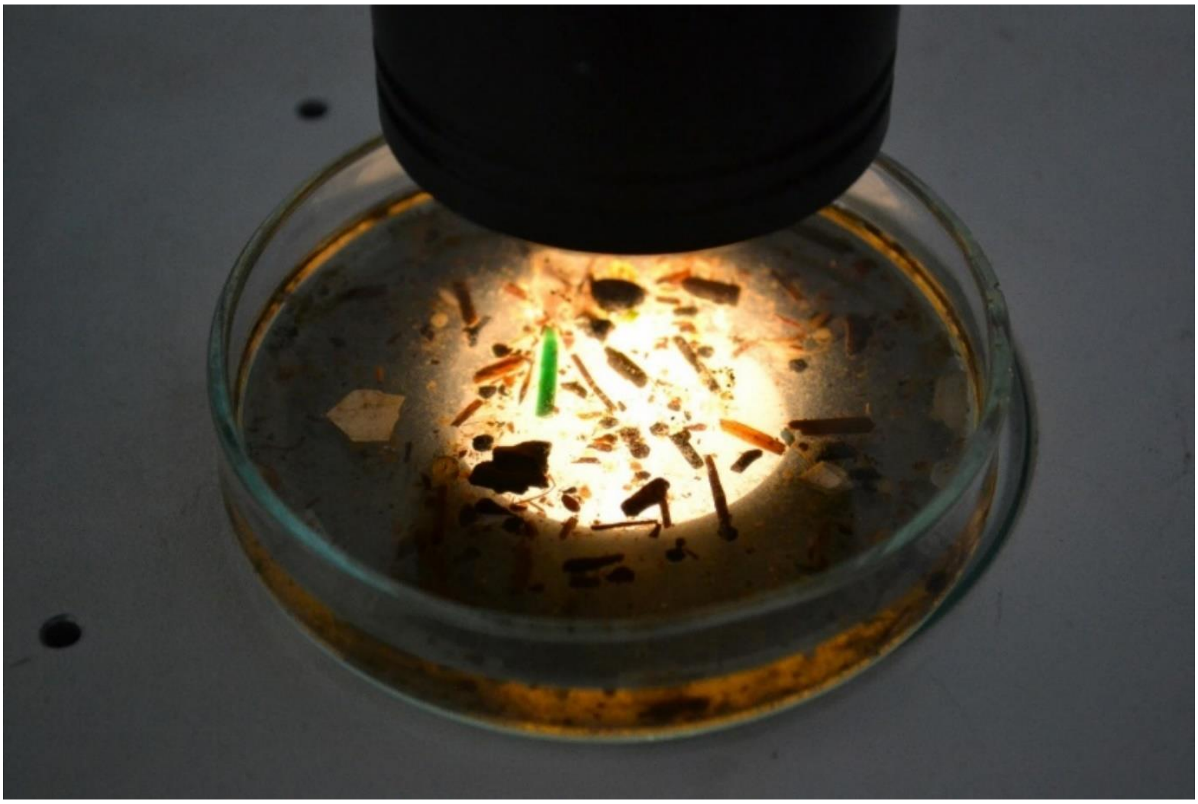

Figure 6-1. *Analysis of microplastics from a marine water sample (Photo: T. Vlachogianni).*

7. Technological Measures

7.1. Introduction

There are a wide range of technological measures for preventing, reducing, and mitigating TWPs. Their effective implementation requires close collaboration across all relevant stakeholders. Some solutions are readily available and can be deployed immediately, while others are still in development or require further research, testing, and validation due to remaining uncertainties—such as the influence of vehicle type, weight, and tyre composition on TWP generation, as well as the environmental consequences of mixed tyre wear particles. Below, technological solutions and their corresponding actionable guidance are organised by the key stakeholder groups responsible for implementing them.

7.2. Actionable Guidance

7.2.1. Industry actors

Eco-friendly tyre design and material selection

- Develop tyres with lower abrasion rates, using less hazardous or more sustainable chemical compounds. (▲ Source Control)
- Encourage compatibility of tyres with road surfaces to reduce the wear of tyres and particle generation. (▲ Source Control)

Vehicle innovation to reduce TWPs generation

- Optimise vehicle weight distribution, torque management, and suspension to minimise tyre wear. (▲ Source Control)
- Explore on-vehicle TWPs capture technologies and integrate them into fleet vehicles. (■ Process Control)

Data collection and reporting

- Participate in harmonised TWPs monitoring initiatives to provide data for regulatory compliance and product improvement. (◙ Enabling Control)

Box 7-1. Electric Vehicles and TWPs: An Emerging Challenge for Zero Pollution.

The transition to electric vehicles (EVs) is a cornerstone of Europe's climate strategy and is expected to deliver substantial reductions in greenhouse gas emissions and exhaust-related air pollutants. However, EVs also raise important questions regarding non-exhaust emissions, including TWPs.

Several studies suggest that vehicle weight is a key determinant of tyre wear (Chae et al., 2024). Because many current battery-electric vehicles are heavier than comparable internal combustion engine vehicles, there is concern that the transition to EVs could lead to increased generation of TWPs per vehicle kilometre travelled. High torque delivery characteristics may also influence tyre wear under certain driving conditions.

At the same time, the relationship between vehicle electrification and tyre wear is complex. Advances in tyre technology, regenerative braking systems, vehicle design, driving behaviour, and future battery developments may partially offset or even reduce tyre wear emissions. Furthermore, the environmental benefits associated with reduced exhaust emissions and improved air quality remain substantial.

Current evidence is therefore insufficient to conclude whether large-scale electrification will result in a net increase or decrease in TWP emissions across the vehicle fleet. Continued monitoring, harmonised measurement methods, and further research are needed to better understand the interactions between vehicle weight, tyre composition, driving behaviour, road conditions, and TWP generation.

From a zero-pollution perspective, the transition to sustainable mobility should address both exhaust and non-exhaust emissions. Future vehicle policies should therefore combine electrification with measures that promote low-abrasion tyres, lighter vehicle designs, sustainable mobility systems, and innovations that reduce tyre wear and capture tyre-derived particles before they reach the environment.

7.2.2. Researchers/Academics

Standardize measurement methods and monitoring protocols

- Develop validated laboratory and field methods for TWPs quantification. (◙ Enabling Control)
- Produce datasets on differences in TWPs generation by vehicle type, tyre type, and road surface. (◙ Enabling Control)

Assess chemical composition and environmental impact of TWPs

- Quantify toxicity, persistence, and interactions of TWPs in soils, freshwater, and marine environments. (◙ Enabling Control)
- Study mixtures of tyre brands and elucidate differences and drivers in their potential ecological effects. (◙ Enabling Control)

Compile and integrate ecotoxicity and exposure data

- Curate datasets into databases (e.g., ECOTOX) and construct robust Species Sensitivity Distributions (SSDs). (◙ Enabling Control)
- Combine acute and chronic toxicity data for improved hazard assessment.

Targeted monitoring and hotspot studies

- Select specific locations and high-risk areas for focused TWPs monitoring. (◙ Enabling Control)
- Generate exposure data to support risk assessment and mitigation. (◙ Enabling Control)

7.2.3. Infrastructure and Service Providers

Implement preventive road-side infrastructure measures

- Implement particle retention systems at or near roadways, including permeable pavements, sedimentation basins, constructed wetlands, and roadside vegetation. (■ Process Control)
- Apply low-abrasion road surfaces and optimised maintenance practices to reduce tyre wear particle formation. (■ Process Control)
- Install and maintain drains, grates, or filtration systems designed specifically to capture tyre particles from surface runoff. (■ Process Control)

Mitigate TWPs release via engineered systems

- Enhance stormwater management infrastructure to trap TWPs before they enter waterways. (● End-of-Pipe Management)
- Upgrade wastewater treatment plants with capture technologies specifically targeting microplastics, including TWPs. (● End-of-Pipe Management)

Participate in TWPs monitoring initiatives

- Provide access to collected TWPs for characterisation, environmental assessment, and research purposes. (◙ Enabling Control)
- Participate in monitoring programs to track TWPs accumulation and assess mitigation effectiveness. (◙ Enabling Control)

8. Social Engagement Measures

8.1. Introduction

Tackling TWPs is not only a technical challenge but also a societal one. Effective prevention, reduction, and mitigation require active social engagement to raise awareness, encourage behavioural change, and promote responsible practices. Despite the increasing attention on microplastics, the specific role of TWPs as a distinct source of pollution remains under-recognised. Many people are still unaware that TWPs are generated and what their potential environmental and health impacts are, a challenge further compounded by the fact that TWPs are often invisible or not easily detectable, making it harder to convey their significance in environmental discussions.

Social engagement measures aim to complement technological and policy/regulatory actions by fostering a culture of sustainable mobility, informed consumer choices, and collective responsibility for environmental protection. Some social measures can be implemented immediately through awareness campaigns, educational programs, and incentives, while others may require longer-term efforts to shift behaviours and attitudes. Below, actionable guidance is organised according to key stakeholder groups responsible for implementing social engagement initiatives.

8.2. Actionable Guidance

8.2.1. Policymakers

Integrate TWPs awareness into public campaigns and environmental education programs

- Develop targeted campaigns to inform the public about TWPs, their environmental and potential human health impacts, and how individual behaviours can reduce emissions. (**Enabling Control**)
- Include TWPs in school curricula, driver education programs, and urban mobility campaigns to build long-term awareness. (■ Process Control)

Promote incentives for sustainable mobility and low-TWPs practices

- Implement subsidies, tax benefits, or reduced fees for public transport, cycling, walking, or use of low-abrasion tyres. (■ Process Control)
- Encourage urban planning that prioritises pedestrian and cycling infrastructure to reduce reliance on private vehicles. (■ Process Control)

8.2.2. Industry actors

Foster consumer awareness on tyre environmental performance

- Provide clear, accessible information on tyre labels, marketing, and sales materials about abrasion rates, lifespan, and TWPs mitigation features. (▲ Source Control)

Corporate transparency and accountability initiatives

- Develop "name and praise" programs to recognise companies leading the way in sustainable tyre technologies. (▲ Source Control)
- Publicly report progress in reducing TWPs to create market pressure for industry-wide improvements. (◙ Enabling Control)

8.2.3. Researchers and Academics

Support evidence-based public communication

- Produce accessible summaries of research findings on TWPs, highlighting uncertainties, environmental consequences, and mitigation options. (◙ Enabling Control)
- Collaborate with policymakers and NGOs to translate complex data into actionable public guidance. (◙ Enabling Control)

8.2.4. NGOs and Civil Society Organizations

Raise public awareness and engagement on TWPs

- Lead campaigns, workshops, and participatory science initiatives to 'monitor' tyre wear particles and microplastics. (◙ Enabling Control)
- Encourage community participation in sustainable mobility programs and advocacy for stricter environmental regulations. (■ Process Control)

Bridge communication between stakeholders

- Act as intermediaries linking policymakers, industry, and the public, ensuring that technical measures are understood and socially supported. (◙ Enabling Control)

9. Key Takeaways

Tyre wear particles represent a diffuse, persistent, and growing source of pollution in Europe that is not yet fully captured by existing policy frameworks. Minimising unintentional microplastic releases from tyre wear is therefore an essential component of a wider strategy for achieving the Zero Pollution Vision 2030 target of reducing microplastics in the environment by 30% by 2030. Addressing this challenge requires a systemic approach that combines strengthened regulation, technological innovation, improved monitoring, and societal engagement. Acting across the full lifecycle—from tyre design and vehicle use to environmental mitigation—will be crucial to achieve meaningful reductions, pollution prevention and advance the EU's zero-pollution ambition for European seas. However, effective implementation will also depend on a clearer understanding of the socio-economic implications of proposed measures, including costs, feasibility, and distributional trade-offs, which remain insufficiently quantified in the current evidence base.

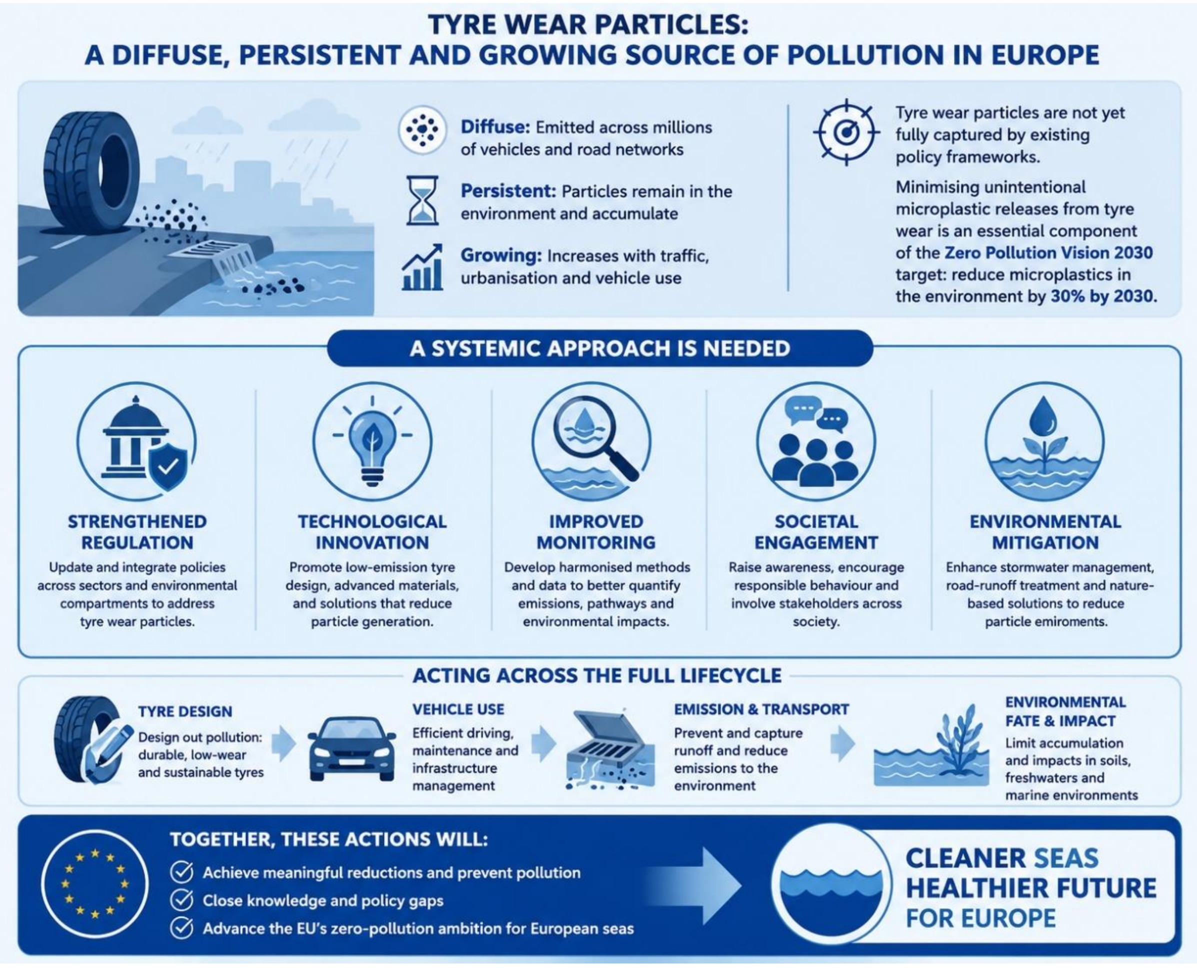

Figure 9-1. Conceptual representation of TWPs as a persistent diffuse pollution source, highlighting the need for a systemic, lifecycle-based approach aligned with the EU Zero Pollution Vision 2030 target.

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List of Abbreviations

Abbreviation	Full Term
BSC	Black Sea Commission
CSOs	Civil Society Organizations
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
HELCOM	Helsinki Commission (Baltic Marine Environment Protection Commission)
ICE	Internal Combustion Engine
IED	Industrial Emissions Directive
MSFD	Marine Strategy Framework Directive
NGOs	Non-Governmental Organizations
NIAS	Non-Intentionally Added Substances
OSPAR	Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
TWC(s)	Tyre Wear Chemical(s)
TWL(s)	Tyre Wear Leachate(s)
TWP(s)	Tyre Wear Particle(s)
UNEP/MAP	United Nations Environment Programme / Mediterranean Action Plan
UWWTD	Urban Waste Water Treatment Directive
WFD	Water Framework Directive

SOS
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