Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit

Niedersächsisches Ministerium für Umwelt, Energie, Bauen und Klimaschutz

Umwelt Bundesamt

# Release of Microplastics into the Marine Environment - State of Knowledge and Options for Action

Berlin Series of Workshops on Microplastics

German Roundtable on Marine Litter
Working Group on Land-based Inputs
Sub-Working Group on „Microplastics“

This publication is a result of the work of the Roundtable on Marine Litter under the auspices of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, the Lower Saxony Ministry for the Environment, Energy, Construction and Climate Protection and the Federal Environment Agency (Umweltbundesamt).

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This report is available digitally as a pdf version at: www.muell-im-meer.de.
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**Available online:**
publica.fraunhofer.de
DOI: https://doi.org/10.24406/umsicht-n-648144

**Suggested Citation:**
Bertling, J., Dau, K., Selig, U., Werner, S., (2022). Releases of Microplastic into the Marine Environment - State of Knowledge and Options for Action. German Roundtable on Marine Litter.72 pages, www.muell-im-meer.de.

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| BLANO | North and Baltic Sea Federal/States Working Group (Bund/Länder-Arbeitsgemeinschaft Nord- und Ostsee) |
| BMUV | Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection |
| BMZ | Federal Ministry for Economic Cooperation and Development |
| BUND | Association for Environmental and Nature Conservation |
| CEPE | European Council of the Paint, Printing Ink and Artists' Colours Industry |
| D | Descriptor |
| DOSB | German Olympic Sports Confederation |
| ECHA | European Chemicals Agency |
| GESAMP | Joint Group of Experts on Scientific Aspects of Marine Environmental Protection |
| HELCOM | Baltic Marine Environment Protection Commission (Helsinki Commission) |
| IKW | the German Cosmetic, Toiletry, Perfumery and Detergent Association |
| IMO | International Maritime Organisation |
| ISO | International Organization for Standardization |
| MARPOL | International Convention for the Prevention of Pollution from Ships |
| MSFD | Marine Strategy Framework Directive |
| MU-NI | Lower Saxony Ministry for the Environment, Energy, Construction and Climate Protection |
| OSPAR | Oslo-Paris Convention - OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic |
| PEE | Plastic emission equivalent |
| PET | Polyethylene terephthalate |
| PLA | Polylactic acid |
| PVC | Polyvinyl chloride |
| RAC | Expert Committee on Risk Analysis of ECHA |
| REACH | European Chemicals Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals |
| RTM | Round Table on Marine Litter |
| SEAC | Expert Committee on Socio-Economic Analysis |
| TRWP | Tire-Road-Wear-Particles |
| UBA | Federal Environment Agency (Umweltbundesamt) |
| UNEA | United Nations Environment Assembly |
| UNEP | United Nations Environmental Programme |
| UNCLOS | United Nations Convention on the Law of the Sea |
| UZ | Environmental target (Umweltziel) |
| WG LBE | Working group on land-based inputs |
| WG SBE | Working Group sea-based inputs |

# 1 Introduction

## 1.1 Preliminary remark

This issue paper is based on the series of workshops on microplastics in the marine environment held in Berlin. This series of workshops is an activity of the German Round Table on Marine Litter (RTM) under the auspices of the

- Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMU),
- Lower Saxony Ministry for the Environment, Energy, Construction and Climate Protection (MU-NI) and
- Federal Environment Agency (UBA).

The aim of the RTM is to concretise and operationalise proposals for measures against marine litter. This includes, among other things, the development of cross-sectoral solutions in a dialogue between experts.

The Berlin series of workshops on microplastics was designed to create an improved knowledge base and to make targeted proposals for the appropriate implementation of the measures of the EU Marine Strategy Framework Directive (MSFD) with regard to microplastics. To this end, two expert workshops were held in 2019 in order to

- compile the state of knowledge on definition, sources, releases, quantities, remains/transfer, ecological and socio-economic impacts and knowledge gaps (29.01.2019, Fraunhofer Forum, Berlin, see chapter 2) as well as
- discuss options for solutions to reduce the use of microplastics in products and prevent the release of microplastics into the marine environment (18/19 November 2019, Federal Environment Agency, Berlin; see chapter 3).

A third workshop in 2020 served to

- incorporate options for action into a structured catalogue of measures, including an assessment of the timeframe for implementation (23.01.2020, Federal Environment Agency, Berlin; see chapter 4).

This report is based on the presentations and handouts of the participants as well as the contributions to the discussion, insofar as they were recorded in minutes. In order to complete the issue paper, further clarifying and in-depth research was carried out on various aspects and important current findings were added.

## 1.2 Political background

In September 2015, the 2030 Agenda for Sustainable Development was unanimously adopted by the member states of the United Nations. (BMZ 2021). Goal 14 of the Agenda agreed on the conservation and sustainable use of the oceans, seas and marine resources. In particular, this includes significantly reducing all forms of marine pollution, marine litter and overfertilization from land-based activities by 2025.

However, the first foundations for international marine protection were laid much earlier. In 1958, the International Maritime Organization (IMO) was founded; from the very beginning, reducing pollution from ships was one of its tasks. In 1973, the IMO coordinated and concluded the MARPOL Convention for the Prevention of Pollution from Ships. In 1975, the London Convention came into force, an international agreement to reduce the dumping of waste at sea by vessels, aircraft and offshore platforms. The 1982 United Nations Convention on the Law of the Sea (UNCLOS) also addressed the conservation of the marine environment and was ratified in 1994. Since then, it has been the main legal basis for regulating human activities in the seas and oceans. In 1996, an extension of the London Convention was passed in the “London Protocol”. It was agreed that any dumping of waste into the sea, apart from those substances explicitly listed on an exemption list, is prohibited (IMO 2021).

In its 3rd resolution in 2017, the decision-making body UNEA of the United Nations Environment Programme (UNEP) coordinated an agreement among states according to which the releases of macro- and microplastics into the oceans must be completely eliminated in the long term through global and regional governance (Grid Arendal 2021). For UNEA 5 in March 2022 it is expected that the opening of negotiations towards a legally binding international Plastics Convention will be agreed on.

In addition to these international agreements and arrangements, two regional agreements exist for the protection of the North Sea and the Baltic Sea, which are particularly relevant from a German perspective. The Helsinki Convention on the Protection of the Baltic Sea (HELCOM) of 1974 is intended to reduce the discharge of pollutants and nutrients into the Baltic Sea and to help rid it of military and other contaminated sites. The agreement was extended in 1992 to include the protection of nature and biodiversity. The renewed Helsinki Convention of 1992 on the Protection of the Marine Environment of the Baltic Sea Area includes all nine bordering Baltic Sea States and the European Union (BfN 2021a). The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic (Paris 1992) brought together two previous Conventions of Oslo (1972) and Paris (1974) into a single treaty and executive Commission based in London. The Convention area covers the Northeast Atlantic from the North Pole to Greenland and the Azores, as well as the entire Western and Northern European coastal waters, including the Barents Sea. Fifteen states and the European Union are members of the Convention. Numerous observer groups are admitted to the meetings. Unlike the Helsinki Convention, for example, this Convention can adopt legally binding decisions in addition to “merely” binding recommendations in the sense of international law. Since 1998, the Convention has also included marine conservation (BfN 2021b). Both OSPAR and HELCOM have already adopted Regional Action Plans on Marine Litter in 2014 and 2015, respectively, which address the main land- and sea-based sources of litter entering the marine environment alongside opportunities for awareness raising and removal of already existing litter (UBA 2019). Both plans were and are currently under revision to reflect new findings and developments.

In 2008, the European Marine Strategy Framework Directive (MSFD, 2008/56/EC) came into force. It called on the member states to take legally binding measures to achieve good environmental status of the seas by 2020 at the latest. In Germany, the implementation of the MSFD is coordinated by the joint North and Baltic Sea Federal/States Working Group (Bund/Länder-Arbeitsgemeinschaft Nord- und Ostsee - BLANO) whereby relevant aspects of the international agreements (OSPAR, HELCOM) are also taken into account. In addition, other relevant environmental EU directives such as the Water Framework Directive, the Habitats Directive and the Birds Directive are also included insofar as they are relevant to marine protection.

There are 11 qualitative descriptors defined in the MSFD for determining good environmental status of the seas. Descriptor 10 states:

*“Properties and quantities of marine litter do not cause harm to the coastal and marine environment.”*

Microplastics are directly addressed in the two assessment criteria D10C2 and D10C3:

**D10C2:** The composition, amount and spatial distribution of micro-litter (‘artificial polymer materials’ and “other”)

- in the surface layer of the water column,
- in seabed sediment and
- on the coastline (optional).

are at levels that do not cause harm to the coastal and marine environment.

**D10C3:** The amount of litter and micro-litter ingested by marine animals (e.g. seabirds, marine mammals, fish or marine invertebrates) is at a level that does not adversely affect the health of the species concerned.

The implementation of the MSFD started in 2010 with a first six-year cycle of status assessment, description of the state of the sea (Good Environmental Status, GES), definition of concrete environmental objectives, implementation of environmental monitoring and definition of a programme of measures. The second cycle followed in 2016 with a new inventory.

With regard to marine litter, the assessment of the status in German marine waters at the end of the first cycle tended to be negative. The beach, seabed and water column are still considered polluted. For the North Sea the status is described as consistently poor, and for the Baltic Sea it is even reported to be deteriorating (Fedder 2019).

BLANO defined the reduction of waste pollution through improvements in product design, waste management, aftercare and public relations as one of the priorities for action in the second cycle. Out of nine measures adopted by BLANO, seven have been started by 2019, two have not yet been started; no measure has been completed so far in the area of marine litter. (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit 2019a; Junge und Weiß 2019).

In Germany, the descriptors of the MSFD have been translated into seven national operational environmental targets. For descriptor 10, the environmental target 5 “Seas without pressures from litter” was formulated and underpinned by three sub-targets (so-called “operational environmental targets”) and indicators (Table 1).

| UZ5 Seas without pressures from litter | | |
|---|---|---|
| | Operational environmental targets | Indicator |
| 5.1 | Continual reduction of inputs and reduction of existing levels of litter lead to a significant reduction in litter that has a harmful effect on the marine environment on beaches, at the sea surface, in the water column and on the seabed. | Number of waste fractions of different materials and categories per area<br><br>Volume of waste fractions of different materials and categories per area |
| 5.2 | Levels of litter in marine organisms (especially microplastics) that are proven to be harmful are tending towards zero in the long term | litter in stomachs of birds (e.g. fulmar) and other indicator species |
| 5.3 | Other adverse ecological effects (such as entanglement and strangulation in items of litter) are reduced to a minimum | Number of entangled birds in breeding colonies<br><br>Number of entangled birds and other indicator species found dead |

Table 1: Operational environmental targets and corresponding indicators for the achievement of good environmental status for the descriptor "Marine Litter"

For the national environmental target 5, concrete measures were further agreed upon (Bund/Länder-Arbeitsgemeinschaft Wasser 2015). The following sub-targets are of particular interest for the present analysis on microplastics:

- UZ5-03: Avoiding the use of primary microplastic particles
- UZ5-09: Reducing emissions and inputs of microplastic particles

The BMU's 2018 report in relation to these targets and the prospects of success in achieving them in the coming years in the North Sea and Baltic Sea is is rather sparse: "*The input and occurrence of litter in the sea must be further reduced. It is expected that the MSFD Programme of Measures 2016-2021, if consistently implemented in Germany, will contribute to improving the state of the environment, which will probably be measurable in the long term. However, due to the longevity of plastic in the marine environment, litter levels are unlikely to decrease significantly by 2020. It is likely that the litter present in the marine environment will fragment and thus a further increase in secondary microplastics can be expected initially. The operationalisation of further indicators for macro litter, micro plastic as well as litter in stomachs of marine animals and further biological impacts will be pursued. As further future work steps it is planned to derive reduction targets for litter in the different marine compartments and marine organisms, to develop procedures for the assessment of adverse impacts as well as to continue existing measures and to implement planned MSFD measures.*"[1] (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit 2019b; 2019c)

The update of the programme of measures for the third cycle (2022-2027) is currently underway. In April, the draft of the updated programme of measures was submitted for public participation, which ended in September 2021. In the course of the revision of the programme of measures, UZ5-03 and UZ5-09 were combined and replaced by the sheet:

- UZ5-10: Prevention and reduction of the input of microplastic particles in the marine environment

The recommendations for action made by the microplastics sub-working group during the third workshop of the Berlin workshop series on microplastics, which were derived from the available knowledge, have been incorporated in their entirety into the sheet for UZ5-10. By December 2021, the new programme of measures should be completed and reported to the EU in March 2022.

The European Commission's Strategy for Plastics continues to be of particular importance regarding plastic emissions in marine protection. It also addresses the sources from which microplastics are produced. The first impact for a regulation project specifically applicable to microplastics is the restriction proposal for intentionally added microplastics of the European Chemicals Agency (ECHA). The restriction proposal and further measures planned within the framework of the Strategy for Plastics are introduced in Chapter 3.

[1] Own translation

## 1.3 Definition and differentiation of microplastics from other plastic emissions

So far, there is no uniform scientific definition of the term “microplastics”.

The term has appeared in the scientific literature since around the year 2000 (Thompson et al. 2004). It was first defined in 2008 by the (National Oceanic and Atmospheric Administration 2017) (NOAA). Due to the widespread distribution of microplastics in the environment, the multitude of possible sources and the resulting relevance of the topic for different areas of life and the economy, numerous different definitions exist today from a multitude of involved actors with partly differing interests (Bertling et al. 2018a; Hartmann et al. 2019).

The previous definition attempts were essentially based on physical properties (shape, size, material) and pragmatic considerations (differentiation from nanoparticles, available measurement technology, etc.). Nevertheless, a problem-oriented definition to determine an upper and lower limit and the relevant substance groups, as well as a link to human- and ecotoxicological findings, has not yet taken place and is still the subject of research. (Bertling et al. 2018b; Hartmann et al. 2019).

Important criteria that are included in the definition are the chemical composition, state of aggregation, solubility, size, shape and structure, mode of origin and, in some cases, the colour of microplastics (Hartmann et al. 2019). The first three criteria essentially describe which groups of substances are counted as microplastics, while the remaining criteria further differentiate the concept of microplastics.

Which groups of substances are included or excluded depends heavily on the respective definitions for the terms polymers[2] and plastics[3], which are sometimes handled differently in business and science as well as in different language areas. Since the rubber industry represents a separate branch of industry and does not belong to the plastics industry, rubber materials (based on elastomers[4]) are sometimes not included in plastics and thus not in microplastics. However, in a scientific context, elastomers are often classified as plastics. Furthermore, it is also recommended from an environmental protection perspective to include rubber materials (Hartmann et al. 2019).

Drawing a clear demarcation between the states solid and liquid, solid and gel-like, and solid and waxy is not trivial since there is not always a clear phase boundary. In the case of polymers, these properties depend strongly on the type and number of monomers, their linkages to each other and the environmental conditions (especially temperature).

Most conventional polymers are insoluble or sparingly soluble in water. Exceptions are for example PVA or PEG. Often, therefore, only insoluble polymers are classified as microplastics. Following the REACH definition for poorly soluble substances, a solubility of < 1 mg/L is usually stated as a limit value (Bertling et al. 2018a; Hartmann et al. 2019). In most cases, only a general distinction is made between soluble and insoluble without specifying exact limit values. Especially in the discussion about polymers in cosmetic products, dissolved, liquid, dispersed and gel-like polymers are also counted as microplastics by some actors (Bund für Umwelt und Naturschutz Deutschland e.V. 2017; Greenpeace e.V. 2017). In most cases, however, only solid particles are referred to as microplastics.

The most commonly used criterion for defining microplastics is size (Hartmann et al. 2019). The prefix “micro” comes from Greek and means “small”. In the scientific context, abbreviated as “µ”, it is a prefix before SI units and denotes a factor of one millionth. In science, the micrometer range is usually given as the range from 1 to 1,000 µm. In addition, the prefix “micro” is also used in scientific and technical language as a qualitative indication of size (similar to “meso”, “macro”, “mega”) in the sense of “small” or “tiny”, without specifying an exact size (microcomputers, microeconomics, etc.).

So far, an upper limit of 5 millimetres has become established for microplastics, which is mentioned in most definitions. This upper limit arose more from pragmatic considerations and the fact that the first microplastics found were mainly pellets on beaches. Plastic pellets are an intermediate product of the plastics industry and are usually between two and five millimetres in size. From a scientific point of view, this upper limit is difficult to justify (Bertling et al. 2018a; Bertling et al. 2018b; Hartmann et al.

[2] Polymers are macromolecules (> 10,000 grams per mole) consisting of chemically similar structural repeating units.

[3] Plastics consist of polymers supplemented by additives, fillers and reinforcing materials.

[4] Elastomers are cross-linked polymers that can be permanently shaped and cannot be remelted.

2019). On the one hand, there are no links to human- and ecotoxicological findings and, on the other hand, new technological trends such as rod-shaped pallets with a length of 10 millimeters (EMS Grivory 2017) question the usefulness of this upper limit.

In addition to the upper limit, a size limit downwards, into the nanometer range, is also being discussed. This limit is of great practical relevance, as many polymers are used in the form of polymer dispersions. They have typical particle size distributions of 50 to 700 nanometers and are often used as binding agents in paints and coatings, as opacifiers, adhesives and coating materials. Depending on the particle size at which the limit would be set, these applications would potentially be affected or exempted from policy and regulatory measures on microplastics. Particularly in the case of polymer dispersions with a broad or even multimodal distribution, classification would be difficult, and the unambiguous metrological determination of particle sizes in the nanometer range is not trivial in every product formulation (Brown 2020).

Some environmental organisations expand the scope of consideration by addressing soluble and nanodispersed synthetic plastics in addition to microplastics. This is justified by the fact that a hazard is not limited to certain size classes. An overview of the definitions of important actors is given in Table 2.

| Organization | Dissolved gel-like polymers | Nano Plastic | Microplastics |
|---|---|---|---|
| NOAA | excluded | included | < 5 mm |
| ECHA 1 | excluded | included | 1 nm to 5 mm |
| ECHA 2 | excluded | partly included | 100 nm to 5 mm |
| ISO/TR 21960 | excluded | separate class < 1µm | 1 µm to 1 mm; large MP: 1 to 5 mm |
| BUND | included | included | 1 µm to 5 mm |

Table 2: Size ranges of the microplastic definition of different organisations or the addressed area of observation (BUND)

For a complete description of plastic emissions, the classification according to ISO/TC 61 has become established in science, whereby mesoplastics are often added to macroplastics:

- Dissolved gel-like polymers
- Nanoplastics (< 1 µm)
- Small microplastics (1 µm to 1 mm)
- Large microplastics (1 mm to 5 mm)
- Mesoplastic (5 mm to 25 mm)
- Macroplastic (> 25 mm).

In addition to size, microplastics are often characterized by the shape and structure of the fragments. In environmental monitoring, the shape and structure partly allow conclusions to be drawn about the sources from which the microplastic could originate. A rough distinction can be made between four structures: spheres, irregular particles, fibres and platelets (Hartmann et al. 2019). In addition, numerous other terms are used, but these are usually used as synonyms for one of the four mentioned (e.g. filaments, fragments, debris, microbeads, etc.). In the context of cosmetic products, the term *microbeads* is often used (Arthur et al. 2008).

Another important criterion for distinguishing microplastics is the way in which they are produced. In principle, microplastics can be divided into three types according to how they are produced:

I. Microplastics intentionally added to the product during the manufacturing phase
II. microplastics, which are created through wear and weathering during the use phase, and
III. microplastics, which are formed in the environment from macroplastics that have been littered, i.e. carelessly disposed of.

Examples of intended microplastics are microbeads in cosmetic products, polymer-coated fertilizers or the plastic granulate on artificial turf pitches. When the products are used, the microplastics can enter the environment.

As a wear product, microplastics are produced during the use of numerous plastic products through abrasion, fragmentation or weathering. Examples include abrasion or weathering of tyres, road markings, paints and varnishes, and plastics used in agriculture.

In contrast to the first two types, microplastics of the third type are only formed after the use phase, through wear and weathering processes in the environment from macroplastics (e.g. plastic waste, discarded tyres, etc.).

The terms primary and secondary microplastics are frequently used to describe the types of formation. However, the classification of category II, i.e. microplastics that form in the use phase, is not always uniform and is sometimes assigned to different types in the various publications. For example, according to OSPAR (2017), primary microplastics are exclusively particles that have been produced in the particular size (category I) and secondary microplastics are particles that are produced during use (e.g. tyre wear, textile fibres) or through weathering (e.g. colour, fragmentation of macroplastics) (categories II and III).

(Boucher and Damien 2017) (Bertling et al. 2018b) on the other hand, suggest that categories I and II should be counted as primary microplastics, but explicitly named as subtypes A and B within these categories. Only category III would then be labelled as secondary microplastics. The rationale for this classification is that this two-tiered classification makes it easier to attribute responsibility. Primary microplastics would then be those that arise in the technosphere during the manufacture of a product (type A) or its use (type B). For both types, the responsibility of manufacturers and distributors should apply - both in terms of environmentally sound product design and in terms of extended producer responsibility. Secondary microplastics, on the other hand, would only be those from littered, illegally disposed of or forgotten plastic objects. Here, the responsibility would lie primarily with users or consumers. Regardless of how the categorization is chosen and named, it is obvious that the currently used division into primary and secondary does not go far enough, as it blanketly shifts many different mechanisms and origins into the group of secondary microplastics.

# 2 Microplastics in the marine environment

## 2.1 Sources and quantities

The sources of microplastics are manifold. It can be an intentional component of products or arise through abrasion, wear and weathering during the use phase. The littering of plastics also leads to the formation of microplastics over longer periods of time, as the littered plastic objects become brittle due to environmental influences, as additives are released and subsequently fragment due to mechanical impact (wind, water, machines, animals).

A release of microplastics occurs if it is not recovered directly at source and immediately after generation (i.e. without significant spatial and temporal offset) (e.g. through cleaning measures such as sweeping or vacuuming with subsequent disposal in a waste collection system[5]). Microplastic releases that enter the sewage system and may be deposited in the sewage sludge should therefore also be considered as emissions and should only be deducted from the amount of microplastics emitted if harmless disposal via a suitable path can be proven.

The release can take place through very different mechanisms along the life cycle. This can be exemplified by colours: First, production losses are possible, which are discharged through exhaust air or wastewater. During processing, overspray (the portion of the paint that does not reach the workpiece) or drip losses often occur, the release of which cannot be completely prevented, especially in outdoor applications. During wet cleaning of equipment and containers, microplastics are subsequently transferred into the wastewater. Paint stripping, grinding or polishing during and at the end of the use phase of paint layers as part of maintenance work leads to the release of very finely divided plastic powders, and the long-term weathering of paint layers also contributes to plastic emissions.

In various studies (Bertling et al. 2021b; Bertling et al. 2018c; Bertling et al. 2018b; Boucher and Damien 2017; Essel et al. 2015b; Hann et al. 2018; Jepsen et al. 2019; Lassen et al. 2015b; Magnusson et al. 2016b; Sundt et al. 2014) have identified a large number of sources that vary widely in terms of the quantities released, the type of plastics (and thus also the additives they contain) and their relevance for marine and soil protection. The following exemplary list shows the variety of possible sources for plastic emissions:

- Tyre wear from motor vehicles, bicycles, sports equipment
- Abrasion of soles
- Abrasion and weathering of paints (especially exterior facade paints)
- Grinding and sandblasting of paint layers
- Droplet losses during painting work
- Wet cleaning of painting tools and residual emptying of paint containers
- Release of infill (infill granulate) and abrasion of fibres from artificial turf pitches
- Abrasion and weathering of sports floors and playing surfaces (running tracks, fall protection, etc.)
- Dust release and losses during processing, transport and landfilling of plastic-containing wastes (automotive waste, construction waste, paper recycling etc.)
- Spreading of composts and fermentation residues containing plastics (incorrect throwing, insufficient separation of packaging, auxiliary materials such as flocculation aids)
- Release of fibres from textiles during washing and drying in households, laundrettes and laundries
- Release of fibres when wearing/using textiles (clothing, technical textiles, e.g. in agriculture, horticulture and landscaping or architecture)
- Losses of plastic pellets due to accidents or cleaning during production, transport and use
- Abrasion and improper removal of road markings
- Release of plastics as aggregates in asphalts due to abrasion or during demolition work
- Release of plastic pellets as packaging material of paving stones
- Release of plastics on construction sites due to abrasion, cutting losses or dust formation during demolition work
- Abrasion of packaging (especially styrofoam for transport packaging)
- Releases of plastics from abrasives and polishes (in the form of binding agents or particulate additives)
- Abrasion and weathering of plastic products used in agriculture (films, planting containers, planting aids, etc.)
- Polymers as coating and auxiliary materials for seeds, fertilizers, pesticides and soil improvers

[5] Less emissions generated during waste disposal and processing.

- Release of plastics from cosmetics, detergents, cleaning agents and cleaning products (microbeads in peelings, opacifiers and film-forming dispersions)
- Abrasion from cleaning equipment with bristles as well as wiping elements made of plastic (brooms, sweepers, windscreen wipers etc.)
- Abrasion of trimmer lines from lawn trimmers
- Release of plastics during drilling, cutting or machining of semi-finished products
- Abrasion of plastic drive elements (belts, gears, slide rails, etc.)
- Abrasion and cutting losses on water and sewage pipes
- Release of plastics from drugs (binding agents or coating)
- Fragmentation of plastics from pyrotechnics
- Abrasion of play equipment (playground equipment, balls)
- abrasion of nets, ropes and other plastic equipment used in fishing and shipping (in particular dolly ropes)
- Abrasion from erasers and cleaning sponges
- Improper disposal of plastic contact lenses
- Abrasion and cutting losses of electric cables (e.g. when laying underground, in wind turbines, etc.)
- Release of glitter and confetti containing plastic due to insufficient cleaning
- Vinyl record abrasion
- Abrasion from kitchen utensils (coated pans, kitchen utensils, plastic cutting boards, etc.)
- Abrasion on conveyor and assembly lines (stone and earth industry, metallurgy, agriculture, food processing, etc.)
- Losses and fragmentation of cable ties (as elements of fences, telecommunication systems, etc.)
- Abrasion or improper cleaning during decoating of marine coatings, hydraulic engineering equipment or buoys
- Release of laser sintering powders due to accidents or improper cleaning
- Abrasion of waxed surfaces or direct release of micronized waxes in case of improper cleaning
- Release of flocculants or ion exchangers during waste water treatment

Despite this large number of sources already identified, it can be predicted that more will be identified and that there will be a future expansion of plastic use to more applications, adding further sources of microplastic emissions.

Plastics consist of polymers, additives, plasticizers, fillers and reinforcing materials. Often they are also combined with other materials or fillers. The polymer content can be very different in the various applications depending on the source. While it is less than 1 % in seed coatings, for example, it can reach 20 to 50 % in paints. A large number of technical plastic products such as tires or PVC sheets for construction engineering are highly filled with plasticizers, fillers and reinforcing materials. On the other hand, films for food packaging or agriculture often contain no fillers and only very small amounts of additives. However, since the hazard from plastic emissions is caused as much by the additives as the polymers, it makes sense to calculate the total masses when estimating releases. Ideally, the additive loads would be recorded substance-specifically and quantitatively, but this is hardly feasible due to a lack of declaration on the part of the manufacturers (Polcher et al. 2020).

The state of knowledge on the mass flows of plastic losses from various applications and the mass flows entering the environment and in particular the oceans as a final sink is still very limited. Studies published in recent years in this area vary widely in terms of methodology, regions considered and number of sources considered. Estimates of total losses from all the plastics applications considered range from about 1.7 to 5.2 kilograms per capita per year. The amount transferred to the aquatic environment ranges from 0.1 to 1.5 kilograms per capita per year. Most authors assume that the emitted amount of microplastics significantly exceeds that of macroplastics. In developed countries in particular, microplastic emissions are both higher than global averages and significantly higher than macroplastic emissions (Table 3).

Emissions are addressed and regulated by very different legal acts. Paints, for example, are products with intentionally added microplastics. These fall under the planned restriction proposal of the European Chemicals Agency (ECHA, cf. Chapter 3.1), but as soon as they have solidified, the restriction proposal no longer applies. Emissions caused by weathering, wear and abrasion could be regulated, for example, by product labels or implementing measures of the European Ecodesign Directive, although this would require the scope of the Directive to be significantly extended, as it currently only relates to products relevant to energy consumption. Corresponding measures are currently being discussed within the framework of the European Plastics Strategy in the corresponding versions for tyres and textiles. The classification and description of the sources in chapter 3 is based on this classification.

| Author/Year | Region | Macroplastic emission [g/(cap a)] | Macroplastic emission [g/(cap a)] | System boundary |
|---|---|---|---|---|
| **(Sundt et al. 2014)** | NO | | *1.590* | *Release into the marine environment* |
| **(Lassen et al. 2015a)** | DK | | 965 - 2.440<br>*106 - 548* | Application losses<br>*Release into the marine environment* |
| **(Essel et al. 2015a)** | GE | | 2.200 - 5.130 | Application losses |
| **(Jambeck et al. 2015)** | World | *615 - 1.628* | | *Release into the marine environment* |
| **(Magnusson et al. 2016a)** | SE | | 1.670 - 3.880 | Application losses |
| **(Boucher and Damien 2017)** | World | | 236 - 660<br>*102 - 320* | Application losses<br>*Release into the marine environment* |
| **(Bertling et al. 2021b; Bertling et al. 2018b).** | GE | 1.405<br>*148** | 2.880 | Application losses<br>*Release into the environment* |
| **(Ryberg et al. 2019)** | World<br>EU | | *390*<br>*896* | *Release into the environment* |
| **(Jepsen et al. 2019)** | GE | *8 - 158* | *1.813 - 3.049* | *Release into the environment* |

Table 3: Estimates of micro- and macroplastic emissions by various authors

## 2.2 Transfer paths

In principle, there are various pathways by which plastic emissions can be transported into certain environmental compartments. A distinction is made between

point emissions:

1 Treated effluents of the sewage treatment plant
2 Rainwater sewers in the separating system
3 Combined Sewer Overflows
4 Directly connected households/industries
5 Rainwater drainage outside towns
6 Direct discharges from vessels and hydraulic structures

and diffuse emissions:

7 Atmospheric transport by wind
8 Washing off (transport by rainwater)
9 Groundwater
10 Transport by animals
11 Waves

Crucial for the transport behaviour of microplastics in the environment are particle size and shape as well as particle density. Filaments and fibers are mainly transported via the wind (Allen et al. 2019; Gasperi et al. 2018). Furthermore, it can be assumed that especially plastics that are lighter than water, e.g. polyolefins or foamed closed-cell plastics, achieve high transfer rates through transport by precipitation runoff. Plastics with densities greater than water (> 1 g/cm³) - elastomers, thermosets and many engineering thermoplastics - are likely to move much more slowly and mainly sediment (Bertling et al. 2018b).

Modeling and empirical analysis of the mobility of microplastics in the environment and the determination of transfer rates are still in their early stages (Bertling et al. 2018b). The large number of sequential and parallel transport processes makes it difficult to realistically model the processes that actually take place. Model-based predictions are therefore only possible to a limited extent. The parameterization of the models is mostly still based on numerous assumptions and expert estimates.

For Germany, studies on soil erosion suggest that transport by wind is more relevant in northern Germany than in southern Germany (BGR 2021). In mountainous and low mountain regions (especially central and southern Germany), however, transport via precipitation water is of greater importance. In particular, heavy rainfall or floods ensure widespread dispersal and distribution. (Scheurer and Bigalke 2018) found in studies of Swiss river floodplains that smaller microplastics in particular also occur in regions with low population density, while mesoplastics were increasingly found in the vicinity of conurbations. They conclude that aeolian transport is an important element in dispersal. Nevertheless, studies on the separation of fibers from the atmosphere showed higher levels for urban regions (Dris et al. 2016a). Therefore, the fibers are probably in a dynamic equilibrium between resuspension and separation. Studies in the French Pyrenees also showed that transport of microplastics via the wind occurs in mountainous regions, although this transport is regionally limited (within 50-100 km) and concerns in particular smaller particles (< 1 mm) and fibres. On a surface set up in the wind, 365 microplastic particles per square meter per day were detected (Allen et al. 2019).

Previous studies strongly focus on transfer to the oceans. Despite numerous knowledge gaps, some estimates already exist. Transfer factors ranging from 19 to 47% are given for the fraction of the source that reaches the ocean (Boucher and Damien 2017; Lassen et al. 2015a; Magnusson et al. 2016a; Sundt et al. 2014).

The share of microplastics that enters the sewer system of wastewater management is largely removed by wastewater treatment plants and transported via sewage sludge to the soils rather than to the oceans in terms of quantity. (Lassen et al. 2015a) therefore also differentiate transfer factors for primary microplastics of type A (added intentionally and generally disposed of via wastewater), for which they give a transfer coefficient of 2 %, and for primary microplastics of type B (from weathering and abrasion in the use phase, which is transported primarily via rainwater drainage), for which they estimate a transfer coefficient of 21 %.

(Piehl et al. 2021) estimate for the Warnow estuary catchment that 49.4 % of the emissions originate directly via inflows. 43.1 % originate from rainwater drainage and 6.1 % from combined sewer overflows, only 1.4 % originate from the outflow of wastewater treatment plants. The data are based on measurements of particle concentrations in the corresponding inflows. The subordinate relevance of combined sewer overflows compared to rainwater drainage was also discussed by (Bertling et al. 2018b).

Using simulations based on three-dimensional flow models, (Schernewski et al. 2021) estimated the microplastic input into the Baltic Sea from urban sources and analysed the retention time. An annual input of about 67 trillion microplastic particles from rainwater drainage, combined sewer overflows and direct inputs was assumed. Surprisingly, the modelling showed only a low average retention time in the Baltic Sea of 14 days. If these results are confirmed, the question arises whether the indicators on microplastic concentrations chosen for descriptor 10, which primarily address surface water and the water column, are correctly selected (cf. chapter 1.2). The distance to the emission source proved to be the main cause of the differences in the amount of microplastic particles deposited on beaches and coasts. Even for polymers such as PET with a density higher than water, it was shown that resuspension effects and subsequent washing up on shores and beaches tend to concentrate on the beaches rather than in the sediments on the seabed (Schernewski et al. 2020). It was shown that the input of microplastics from urban sources into the Baltic Sea could be halved if only the proportion of annual wastewater entering the Baltic Sea via combined sewer overflows was reduced from the current 1.5% to 0.3%. At the same time, the total discharge would only be reduced by 14 % if all wastewater were treated and all sewage treatment plants were equipped with a third treatment stage (Schernewski et al. 2021).

## 2.3 Fate and environmental concentration

The global and ubiquitous spread of plastics has led to plastics also being seen as an important indicator and potential marker in the debate on the introduction of a new Earth age (Anthropocene) (Zalasiewicz et al. 2017). The existence of microplastics has now been demonstrated in all areas of the environment. In surface waters and the water column (GESAMP 2015; Geyer et al. 2017; Gregory and Anrady 2003), in sediments of the seabed (Ling et al. 2017), in soils (de Souza Machado, Anderson Abel et al. 2018), in agricultural land (Liu et al. 2018), in remote regions such as the Pyrenees (Allen et al. 2019), the Arctic (Alfred Wegener Institute 2018), in drinking water (Münsterland-Emscher-Lippe Chemical and Veterinary Investigation Office 2018), in food (Dehaut et al. 2016) and in humans themselves (Liebmann et al. 2018). Microplastics are ubiquitously distributed.

Persistence of plastics to mechanical and biological degradation processes ensures long environmental retention times (Bertling et al. 2018b; Bertling et al. 2018c; Emadian et al. 2017). However, little is known to date about the actual degradation times of plastics in natural environments. There are numerous experimental studies on the degradability of plastics from standardized laboratory tests.[6] For environmental media such as soil, lake/river and sea water, river or sea sediments, however, only limited generally valid conclusions can be drawn from the results of these experiments, since comparable experimental methods and models for data-based extrapolation for real environmental environments are

[6] E.G.: Yabannavar and Bartha (1994); Kasuya et al. (1997); Rutkowska et al. (2001); Tachibana et al. (2013); Deroine et al. (2014); Emadian et al. (2017).

still lacking. Degradation times of several hundred to a thousand years are assumed.

More microplastic is emitted annually than is decomposed by mechanical and biological degradation processes. In the future, this will lead to a further massive increase in the amount of plastic in the environment and specifically microplastic, as large pieces of plastic gradually break down into microplastic. This foreseeable increase in quantities, together with the findings to date on proven and suspected harmful effects, suggests that action should be taken in accordance with the precautionary principle of environmental law in order to limit the quantities of microplastics entering the environment. (Bertling et al. 2018b). A corresponding social consensus and willingness to act is already evident in the case of plastic litter (mostly macroplastics). Since microplastics cannot de facto be recovered in relevant quantities and without further negative environmental impacts, even through clean-ups, and since sensible environmentally compatible technical innovations for recovery are not in sight, the urgency for efficient prevention strategies is to be rated all the higher here.

### 2.3.1 North Sea

(Maes et al. 2017) give a particle count of 0 to 1.5 particles per cubic metre of water and of 0 to 3,146 particles per cubic metre of sediment with a size spectrum 355 to 5000 µm for the southern North Sea. Furthermore, the authors found that irregular fragments dominated in the water, while only spherical particles and fibers were found in the sediments. Furthermore, it was found that as the particle size decreased, the number of particles in the sediments increased, which could be interpreted as an indication of fragmentation from macro- to microplastics. Leslie et al. obtained similar ranges of measurements in river, estuarine, and marine sediments (10 to 3,600 particles per kilogram (DM))[7]. Furthermore, they found a clear gradient from land to river that may serve as evidence for land-based inputs (Leslie et al. 2017).

A more recent study by (Lorenz et al. 2019), which sampled sublittoral sediments and surface water at 24 stations, also detected microplastics ranging in size from 11 to 5,000 micrometers. Microplastic concentrations of 2.8 to 1,188.9 particles per kilogram of sediment (DM) and 0.1 to 254 particles per cubic meter of surface water were detected in all samples examined. The majority of the particles were less than 100 micrometers in size. The main polymer types were polypropylene, polyacrylates, polyurethanes (paint particles) and polyamides. Nevertheless, particle numbers and polymer types varied considerably.

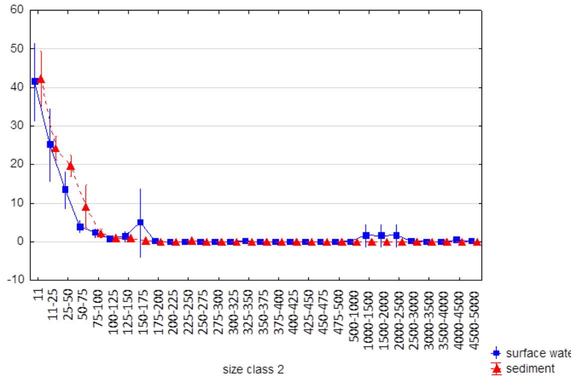


Figure 1: Particle number distribution of microplastics in sediment and surface water according to (Lorenz et al. 2019)

### 2.3.2 Baltic Sea

85 million people inhabit the drainage area that discharges into the Baltic Sea. As it is also an inland sea, the Baltic Sea is under particularly high anthropogenic pressure compared to other seas and oceans. This also implies a high potential for plastic inputs. A holistic study must take into account the beaches, estuaries, the open Baltic Sea in terms of the water surface and water column and the seabed, as well as the main biological impacts of plastic waste in the sea.

The investigation of microplastics from urban sources using simulations based on three-dimensional flow models showed an average concentration of 1.4 particles of the lightweight plastics polyethylene and polypropylene per square meter of sea surface. For the seabed, the average concentration of heavier PET was calculated to be 4 particles per square meter of sediment surface area (Schernewski et al. 2020).

Various studies agree that the greatest pollution of microplastics is found near the coast in the vicinity of emission hotspots. In contrast, significantly lower concentrations were found in the open Baltic Sea (Gewert et al. 2017; Schernewski et al. 2020). For example, up to 379 microplastic particles per kg dry weight were detected in sediments of the Warnow estuary and only 2 microplastic particles per kg dry

[7]7 DM = dry matter, dry weight

weight in the Baltic Sea estuary (Enders et al. 2019).

(Haseler et al. 2020) examined 190 beach samples in 35 Baltic Sea regions for micro- and meso-litter (2-25 mm) using the sand rake method. Over an area of 10,271 square metres, 9,345 pieces of litter were found, of which 53% were identified as plastics. Industrial pellets (19.8%), unidentifiable plastic pieces of 2-25 mm (17.3%) and cigarette butts (15.3%) were detected most frequently.

### 2.3.3 Methods of analysis

To measure microplastic concentrations, especially in open waters, reproducible, contamination-free methods are required that can process large volumes of liquid and also separate very fine plastic particles regardless of their density. Corresponding devices have already been developed (among others (Lenz and Labrenz 2018). In the medium term, they should be standardized to increase the comparability of measurements.

The challenge in detecting microplastics already begins with the sampling. While it is still quite easy to obtain sufficient samples of sediments in which microplastics are more concentrated, the detection of microplastics in water requires the filtering of large quantities. Nets are only suitable up to certain size classes, as smaller microplastics cannot be detected by them, and they are also usually made of plastic themselves. This makes them a potential source of contamination. Closed, plastic-free filter systems, in which the water is sucked through the filters, are therefore necessary (Lenz and Labrenz 2018).

Samples from all environmental compartments must be prepared prior to particle-based chemical analysis. Depending on the matrix, different methods and procedures can be used to separate the interfering organic and inorganic natural particles from the plastics without corroding them in the process (Enders et al. 2019). Working in a plastic-free environment in the laboratory is important to avoid contamination during analysis. In order to reduce measurement errors and improve the comparability of results, Enders et al. have developed a detailed flow chart for method selection (Enders et al. 2020).

Extraction of microplastics from biota is less well developed; however, there are indications that microplastics can be well purified from biotic samples via solvents such as hexane (Lenz et al., 2021, submitted).

In the meantime, a large number of methods have been established for polymer analysis. Basically, a distinction must be made between thermoanalytical and spectroscopic methods. The application of these methods basically depends on the task of the analysis - i.e. whether a mass-based analysis or particle-based analysis is required. For a continuous analysis from source to sink, which would make sense from an environmental regulatory point of view, a comparison of the recommendations and methods for terrestrial, fluvial and marine analysis should be carried out. A comparison of all tested methods and an assessment of the applicability was carried out by the recommendation for action of the projects of the research focus “Plastics in the environment” (Brown 2020). Automation is required for comprehensive monitoring. For this purpose, spectral databases have already been created and published, among others (Primpke et al. 2018).

### 2.3.4 Monitoring the occurrence of microplastics in the North and Baltic Seas

The clear local variations in particle numbers and polymer types show that a realistic picture of the fate and occurrence of microplastics can only be provided by monitoring over a wide area.

Descriptor D10C2 requires monitoring of micro-waste in the surface layer of the water column and on the seabed, and optionally on the coast.[8] Micro-waste should be monitored in such a way that the waste inputs can be attributed to the respective sources (e.g. harbours, marinas, wastewater treatment plants, rainwater drainage systems). While the monitoring of macroplastics on beaches is already established via beach litter monitoring, the monitoring of microplastics is still in an early development phase. Concrete candidates for an expansion of monitoring are currently being discussed (status 2021):

- Microplastics in sediments (OSPAR/HELCOM)
- Microplastics in the water column (HELCOM)

It would be useful to harmonise the activities of OSPAR and HELCOM as well as the EU's MSFD Technical Group on Marine Litter (TG ML). This is currently being addressed in the HELCOM BLUES project and the revision of the TG ML monitoring

[8] Descriptor D10C3 is discussed in chapter 2.4.3.

guidelines. The aim is a joint monitoring protocol that enables harmonisation with the regional convention on the protection of the seas and the MSFD.

For a meaningful link between the concentration determined by monitoring and the quantities emitted from various sources, it would be useful in future to report not only the particle numbers but also the masses per square metre (water or soil surface) or kilogram of dry weight (soil, sand, sediment). Only in this way can the contents in the environmental compartments be related to the emissions from different sources.

The IOW Rostock has developed a framework and calculation method for quantifying plastics on beaches. However, the method is only suitable for large microplastics (> 2 mm) and mesoplastics. The authors critically discuss whether a comprehensive monitoring of microplastics < 1 mm is feasible at all given the current effort for the analysis of microplastics, especially in heterogeneous matrices.

In order to identify relevant sources and input pathways in addition to the occurrence of microplastics in the environment, consideration should also be given to recording microplastics e.g. in river estuaries, buildings of water management including sewage treatment plants, harbours, shipyards and possibly offshore facilities or in vegetation areas along rivers.

### 2.3.5 Making data available

Since the investigation of microplastic pollution in the environment is very complex, the results of the investigations often only represent highlights. Furthermore, sampling and analysis are very complex, so that data sets from the environment will also be very limited in the future. A comparison of different studies is usually made more difficult by the fact that even the basic principles of the survey (microplastic size classes, processing methods, analytical techniques, etc.) differ greatly.

The IOW informed about a marine plastic database (MPDB), which was developed with partners from the Baltic Sea region. Here, microplastic particles are geo-referenced and characterized with regard to polymer type, size, shape, color, etc. This database allows general import/export as well as data exchange with other international and national marine litter databases and offers the possibility for data quality assurance and assessment, spatial visualization and statistical analysis. The MPDB is currently hosted on the IOW server at 192.124.245.26 (micropoll.io-warnemuende.de). The MPDB is used across projects and is available to public institutions upon request from the IOW.

## 2.4 Effects

The presence of plastics in the environment must not be confused with the effects on the environment and human health. Basically, the following effects can be distinguished:

- Mechanical effects on marine organisms, in particular by entanglement and ingestion and on marine (sensitive) habitats (smothering, damage)
- Chemical-toxicological effects due to polymers or their degradation products
- Chemical-toxicological effects due to additives and fillers
- Chemical-toxicological effects due to adsorption/desorption of pollutants (vector function)
- Ecosystem effects such as formation of barriers, colonisation (e.g. biofilms) of plastic parts or transport (e.g. carry-over) of species

In addition, the aesthetic impact on the natural environment also plays a major role, particularly in the case of plastics, and in many debates, this seems to be the point on which all stakeholders - manufacturers, processors, users, recyclers - are quickest to agree on.

### 2.4.1 Effects in the natural environment

The accumulation of plastic in the environment represents a massive damage of terrestrial and aquatic ecosystems. In terms of mechanical effects, a high degree of entanglement and strangulation, as well as regular passive and active ingestion, especially in confusion with food, with sublethal and lethal consequences, is observed above all in seabirds, marine mammals, fish and turtles. In the case of seabirds, seals and fish, there is growing evidence of negative effects down to population level. The extent of entanglement depends mainly on the size and shape of the plastic objects as specific risk factors in relation to the affected species, as well as on the number of plastic objects in the environment. Entanglement and associated injuries have so far been addressed primarily as a problem in relation to macroplastics, with fibrous waste items such as packaging straps, net fragments and ropes being particularly problematic.

In some species, ingestion of litter particles meanwhile reaches large proportions of the total population (Bergmann et al. 2015; Derraik 2002; GESAMP

2015; Geyer et al. 2017; Gregory 2013; Li et al. 2016; Werner et al. 2016). Ingestion of garbage particles can lead to internal injuries and blockages, but also to starvation, as the filled stomach suggests a constant feeling of satiety. Laboratory experiments have so far demonstrated negative effects of microplastics on overall constitution and reproductivity at lower trophic levels. Harmful effects have been observed in particular on small and water-filtering organisms (Besseling et al. 2013; Boerger et al. 2010; Wagner and Lambert 2018; Wright et al. 2013) but also on algae (Bhattacharya et al. 2010; Kalcikova et al. 2017) partly due to physical effects of the polymer particles themselves, partly due to the additives they contain.

Corresponding effects under real natural conditions are considered to be obvious, but the extent and relevance are difficult to assess so far due to the low transferability of laboratory and real conditions.

In addition to the harmful effects of microplastics per se, there is also the question of the extent to which plastics and especially microplastics as a transport medium increase exposure to pollutants; this is  insufficiently investigated. Real pollutant concentrations, partition equilibria and the question of whether certain species preferentially take up microplastics are important here.

Plastic objects, like all objects, are colonized by biofilms. (Oberbeckmann et al. 2021) showed that the biofilm composition of natural particles (wood) and polymeric particles (PS) differ significantly depending on the nutrient supply - especially in saline environments. (Kirstein et al. 2018) have also identified differences in biofilms between glass and plastic, but also a common base biofilm composition for various synthetic polymers that differs only slightly. Whether and to what extent these differences between polymers and non-polymers, or even between different synthetic polymers, are relevant on an ecosystem or ecotoxicological level is still unclear.

It is assumed that plastics can act as a vector for drift of species including invasive species. The extent to which this drift of plastics is relevant compared to natural and other anthropogenic transport media is still poorly understood. Due to the very low degradation of the plastic, it is generally expected that the effect as a vector could be relevant especially for very long and far transport processes.

In addition, it is assumed that the high degree to which plastics accumulate in different habitats will have an influence on interspecific coexistence. Plastics can favour individual species and disadvantage others, so that existing equilibria are disturbed and new ones emerge. Plastic litter furthermore damages and destroys (sensitive) habitats such as coral reefs and soft sediments. This can be e.g. be in the form of derelict fishing gear or parts thereof, which cover sandy sediments in tidal zones and organisms attributed to them.

The negative effects on marine ecosystem services also result in adverse socio-economic impacts. From the few reliable surveys available, it can already be assumed that the costs of avoiding plastic emissions are lower than the monetarized damage caused by inaction.

Even if the transfer of microplastics in the food chain has been proven, it is unclear what concrete risks to human health are associated with it. Regardless of the actual risk, there is hardly any acceptance among consumers for food containing microplastics.

Plastics contain numerous additives, such as halogenated flame retardants, plasticizers, organometallic stabilizers, catalysts, organic or heavy metal-containing dyes, and many more. In addition, there are environmentally relevant residual monomers such as bisphenol A, methyl methacrylate, styrene, vinyl chloride or formaldehyde (Bertling et al. 2018b). Many of these additives are known to have harmful effects on humans and animals. Previous studies have shown that microplastic emissions can lead to a transfer of pollutants in the environment by dissolving out of the additives (Kitahara and Nakata 2020).

### 2.4.2 Experimental studies on the effects

The specific eco- and human toxicological hazards of microplastics have not yet been adequately researched (GESAMP 2015; Wright and Kelly 2017); much is still unknown. Interrelationships are suspected rather than proven. Against this background, systematic experimental studies are urgently needed.

In principle, the ingestion of microplastics is not a problem for most organisms as long as they excrete it again after ingestion. Corresponding excretions could be observed by (Batel et al. 2016) in the model food chain of crayfish larvae (Artemia sp. Nauplii) and zebrafish (Danio rerio). However, larger microplastic particles in particular can also lead to the mechanical impairments described above.

In principle, relevant ecotoxicological effects are to be expected primarily when particles enter cells or tissue (translocation). This is more likely the smaller the particles are. (Batel et al. 2016) found a small amount of translocation into tissue (intestinal cells) in brine shrimp and zebrafish. Experimental evidence of translocation was found in mussels. Various effects such as oxidative stress, DNA damage, neurotoxicity could also be demonstrated (Ribeiro et al. 2017).

In particular, the effects of very fine particles down to the nanometer range, e.g. in polymer dispersions or as a result of a particle size reduction due to degradation or fragmentation, should therefore be investigated experimentally.

Increased exposure to contaminants that are not original components of the plastic has been widely discussed and experimentally investigated. In this context, it is assumed that a sequence of sorption, ingestion and desorption of plastics, and microplastics in particular, results in the concentration and availability of pollutants. In the work of (Batel et al. 2016) it was also shown, using the example of benzpyrene, that microplastics can act as vectors for pollutants. In other studies, however, it was found that the opposite effect is also possible. Microplastics can compete with organisms for the pollutants and cause a kind of shielding effect (Scopetani et al. 2018). Whether and when a negative effect occurs depends to a large extent on the partition equilibria between pollutant, organism and aqueous environment and the corresponding sorption kinetics. Other carriers that could act as vectors are also in competition with microplastics (Koelmans et al. 2016).

Kesy et al. (2016) showed, in analogy to the studies in the North Sea and Baltic Sea (Kesy et al. 2016; Kirstein et al. 2018; Oberbeckmann et al. 2021), that bacterial colonization in the form of biofilms differs significantly for polystyrene and glass particles. During the subsequent passage through the digestive tract of the lugworm (*Arenicola marina*), the biofilms converged after passage. However, the extent to which the greater reduction of the biofilm in the case of polystyrene is ecotoxicologically relevant, could not be clarified.

(Lenz et al. 2016), (Burns and Boxall 2018) refer to the clear discrepancy between laboratory conditions and the real situation with regard to the experimental studies carried out to date on the effects of microplastics. One criticism cited was the setting of far too high test concentrations of the microplastic in the experiments. For example, of 29 studies, only two took place with a microplastic concentration of < 0.1 milligrams per liter. The remaining studies, however, had concentrations of up to 100 milligrams per liter. The extent to which the effects of such high concentrations can be transferred to realistic environmental concentrations is questionable. There is a particular need for an overarching theoretical underpinning and evaluation concept for the expected effects, as well as the performance of long-term studies at low and realistic particle concentrations. At the same time, particle and polymer types should be used which correspond to those of real plastic emissions. The use of uniform particle standards, on the other hand, is not very expedient.

Also, with regard to particle sizes, it appears, in terms of toxicological relevance, that particles in the nanometre range are particularly relevant for the aspects of translocation and vector function, and macroplastics in terms of internal injury, constipation and entanglement. In this regard, future experimental studies should cover all particle sizes of plastic emissions with reference to the relevant characteristic dimensions of the organism or tissue under study in a better way. Real aged particles should also be used in comparison to particle standards.

### 2.4.3 Monitoring of environmental impacts

In order to monitor the effects of plastics in the marine environment, various monitoring approaches are being pursued, developed and standardised by the EU, OSPAR and HELCOM. The quality of monitoring depends fundamentally on the objectivity, spatial and temporal representativeness and validity of the results, as well as on the reliability and reproducibility of the sampling and analysis methods. To monitor the effects of microplastics, the following study approaches have already been established as common indicators under OSPAR:

- Stomach contents of stranded dead fulmars (Northern fulmar, agreed objective: less than 10 % of birds found to have < 0.1 g plastic particles in stomach)
- Plastic particles in the gastrointestinal tract of stranded, dead or by-catch sea turtles (Loggerhead turtles, trends in amounts and composition of ingested litter particles > 1mm).

The established monitoring is limited to particles > 1 mm, so that currently only large microplastics are measured (European Commission - Joint Research Centre 2013). (van Franeker et al. 2016) show that in the regions studied, 50 to 90% of the dead fulmars examined had more than 0.1 grams of plastics in their stomachs. As of 2019, there was still no positive trend towards a reduction (status of 2019).

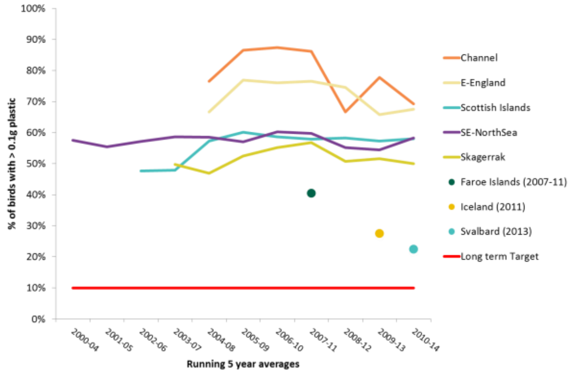


Figure 2: Proportion of dead birds with more than 0.1 g of plastic in stomach contents (OSPAR Commission 2019)

Other monitoring approaches being discussed to address additional marine regions and impact categories include plastic particles in shellfish and the stomachs of various fish species and shearwaters, and the use of plastics as nesting material in seabird breeding colonies and associated entanglement and strangulation rates.

Scientific projects should help to provide the basis for the establishment of a coherent long-term monitoring for marine litter, e.g. in the context of correspondent r&d research, where pilot monitoring methods for ingestions of plastic particles in marine mammals, fish and mussels in the German North and Baltic Sea and for the application of plastic litter in sea birds breeding colonies with associated entanglement rates were developed and tested (UBA, in publication) or in an investigation of microplastics in edible fish such as herring, mackerel, sprat, etc. The investigation takes place twice a year in seven North Sea and Baltic Sea areas on up to 20 individuals per area. The investigation will take place twice a year in seven North Sea and Baltic Sea areas on up to 20 individuals per area (Thünen Institute 2021).

There is currently no established monitoring programme that specifically addresses the effects of microplastics in the size range up to 1 mm. A variety of studies on different environmental compartments are available, but their results are often not comparable and cannot be used as a benchmark for assessment. Further strategic developments on the part of the EU, OSPAR and HELCOM should address this deficit in a coordinated manner and be flexibly adaptable to changes in the marine environment. Pilot projects could provide valuable experience for later implementation in monitoring programmes. In the long term, a permanent concept including funding is required for monitoring beyond temporary projects.

The relevance of microplastic monitoring is also given with regard to consumer protection. The Federal Institute for Risk Assessment (BfR), for example, does not consider itself in a position to issue a risk assessment for microplastics ingested via foodstuffs, as no reliable findings on the occurrence and composition of microplastics in foodstuffs are available to date (Federal Institute for Risk Assessment 2015).

## 2.5 Assessment

An established methodology for assessing potential environmental impacts is the life cycle assessment method standardized in ISO standards (DIN EN ISO 14044; DIN EN ISO 14040). This should be seen as complementary to assessments of the biological impacts of marine litter on marine life in the context of marine protection.

Specific impact assessment methods have been developed for certain environmental impacts, e.g. greenhouse gas emissions, shortage of resources, overfertilization or acidification, which allow a standardised approach to the assessment and make the results obtained comprehensible and comparable. Such an impact assessment methodology does not yet exist for the consideration of the effects of plastic emissions (Sonnemann and Valdivia 2017).

The following effects of plastic emissions could be subject to assessment:

1) Loss of resources/carbon
2) Chemical-toxicological effects of additives and monomers
3) Physical-toxicological effects of particles/objects
4) Effects on marine ecosystems, habitats and species composition
5) Socio-economic impact

Initially, emissions could also be described as resource losses (here: losses of carbon) (1). For this purpose, first approaches exist that focus on the losses of resource base in the technosphere (anthropogenic base) (Zampori and Sala 2017). For highly emitting sources, where a large part of the plastic used is not recovered, a corresponding accounting would be conceivable (e.g. for tyres, paints, adhesives, microbeads in cosmetics). For many other sources from which smaller proportions are emitted, however, the loss of carbon in the overall balance would already be lost in the accuracy of the data (e.g. fibre losses in textile washing, abrasion and cutting losses in building materials, etc.). Furthermore, the only effect would be the loss of resources per se; subsequent eco- and human-toxicological effects would be completely ignored in this variant of integrating plastic emissions into life cycle assessments. It would also not be possible to differentiate between aquatic and terrestrial effects.

The mapping of chemical-toxicological effects (2) is feasible for the additives contained in plastics and is also practiced in life cycle assessments. Nevertheless, suitable data (characterization factors) for calculating the effects are available today for only 18 % of the additives (Hauschild et al. 2018). Missing data could, however, be estimated using AI methods, for example (Song et al. 2017).

For microplastics as such, there is still insufficient information available to allow calculation of the eco- and human-toxicological effects in the same way as for additives or other pollutants. In particular, effects caused by the size or shape of the particles and also those caused by extreme persistence cannot be adequately taken into account with the current method.

Against this background, the persistence-weighted plastic emission equivalent (PEE) is being developed as a new impact category (3) in the “Plastic Budget” project by Fraunhofer UMSICHT. Here, the emitted mass flow of a plastic is distributed to the final environmental compartments that can be considered as sinks. The plastic mass flow taken up by an environmental compartment is multiplied by the typical degradation time and related to a reference time of one year. Accordingly, rapidly degradable polymers have low PEE, while poorly degradable polymers have high PEE. At the same time, emissions in compartments where the plastic shows good degradation will contribute less than emissions in compartments where the plastic is particularly persistent.

Since the exact degradation rates for plastics, which degrade very slowly, can hardly be determined, a time horizon of 100 years is applied in analogy to the procedure for greenhouse gases. This means that all polymers with longer degradation times are assigned the same PEE. From an environmental perspective, this increases the pressure to innovate in the direction of easily degradable plastics (Maga et al. 2021).

The developed methodology offers the advantage that, on the one hand, the precautionary principle is already taken into account today with the weighting via persistence. In addition, the calculation architecture has been selected in such a way that the assessment methodology can be easily extended in the event of future growth in knowledge about the eco- and human-toxicological or ecosystem effects (4) of microplastics. At this stage of the assessment, however, polymer type, particle size and shape are sufficient to estimate degradation times. The transfer factors to calculate the distribution starting from a first compartment into the final compartments are currently being compiled and made available by Fraunhofer UMSICHT.

A socio-economic assessment (5) would also be possible. Here, for example, the costs of restraining or reducing emissions or the complete abandonment of the use of plastics would be compared with the costs and the benefits that result from avoided damage to e.g. fisheries, aquacultures or tourism. However, the quantitative estimation of the benefits in particular is to date possible for initial issues only, such as cleaning costs for coasts and beaches.

## 2.6 Interim summary

For a problem-adequate consideration of plastic emissions in the form of microplastics, it is important that the characterization does not refer exclusively to particle size, but also includes persistence in the sense of precautionary orientation. Relevant effects and environmental impacts can be derived from persistence.

The material scope of the term microplastics is still not clearly defined, in particular with regard to the aggregate state and size classes. An inclusion of elastomers and of dissolved and gel-like polymers should therefore be further pursued and examined.

Furthermore, in order to derive measures efficiently, it is important to identify all input pathways for microplastics, to quantify them and to know the final sink(s) in the environment. In particular, there is still little knowledge about the transfer rates from the technosphere to various environmental compartments and about the redistribution processes that take place there.

With regard to smaller microplastics and nanoplastics, there is an urgent need for investigations into long-term ecotoxicological effects. Effects are suspected above all for particles in the nanometre range. So far, translocation in mussels and a reduction in vitality and reproduction in fish have been documented under laboratory conditions. These effects have not yet been demonstrated for concentrations measured in the environment. Studies under realistic conditions are therefore urgently needed. Under certain circumstances, microplastics can act as vectors for other pollutants present in the environment, but it is still unclear under which conditions and for which substances this is the case. Systematic studies are lacking here.

While particles > 1 mm (large micro-, meso- and macroplastics) are already recorded by existing monitoring in some compartments, monitoring for smaller microplastics has yet to be established (pilot studies, site selection, harmonization of methodology). Initial recommendations for action have been made, among other things, by the projects of the research focus "Plastics in the Environment" and pilot investigations within the framework of BMU/UBA research and development projects. Based on these findings, the further development, standardisation, harmonisation and automation of sampling, processing and analysis is necessary.

# 3 Avoidance, reduction of microplastic input

## 3.1 Intentionally added microplastics

### 3.1.1 Regulatory aspects

As part of its plastics strategy, the European Commission has asked the European Chemicals Agency (ECHA) to examine and develop a Europe-wide regulation for the use of intentionally added (primary) microplastics in various products under the REACH Regulation.

Based on this, ECHA published a first restriction proposal (ANNEX XV Restriction Report) in January 2019. The proposal aims to reduce microplastic emissions within the European Union by 500,000 tonnes over a 20-year period. The restriction proposal was subsequently subject to a public consultation, during which 477 individual comments were received and led to various adjustments.

Based on this, two ECHA expert committees for risk assessment (RAC) and for socio-economic analysis (SEAC) have delivered their opinions. The restriction proposal, including a joint opinion of the two risk committees, will now be submitted to the European Commission for the political decision-making process and then forwarded to the European Parliament and the European Council for consideration and decision. The decision is expected in 2021. Subsequently, agreed substance restrictions would be included by ECHA in Annex XVII of the REACH Regulation.

The main objective of the proposed restriction is to prohibit the placing on the market of products containing microplastics after its entry into force. A mass fraction of microplastics of 0.01 % is already sufficient.

Of particular relevance is the regulated particle size range, which is currently specified from 1 nanometre to 5 millimetres (or, in the case of fibres with a length-to-diameter ratio greater than 3 nanometres, up to 15 millimetres).

While the upper limit of 5 millimeters is not discussed, the lower limit is controversial. ECHA's Socio-Economic Analysis Committee (SEAC) recommends raising it to 100 nanometers due to a lack of analytics. ECHA's Risk Assessment Committee (RAC), on the other hand, recommends full inclusion of nanoparticles (keeping the original lower limit of 1 nanometer) (European Chemical Agency ECHA 2020). In principle, the lower and upper limits are largely arbitrary. Causal relationships to environmental effects are missing (cf. Chap. 1.3). At the same time, it is unclear whether emissions of plastics outside the scope of regulation will not also require regulation and whether there will be corresponding circumvention strategies on the part of manufacturers or companies placing them on the market. (Bertling and Özdemar 2021).

Furthermore, a particle already counts as microplastic if the mass fraction is more than 1 % polymer, so that microcapsule systems and agglomerates with polymer binders, for example, are also largely included.

Exceptions are provided for:

- Natural polymers: The only permissible chemical modification is hydrolysis. Furthermore, biodegradable polymers are excluded (cf. chapter 3.3)
- Microplastics for industrial and medical applications and products subject to the European Fertiliser Regulation

- applications in which complete retention over the entire life cycle and harmless thermal recovery can be guaranteed
- Microplastics that are permanently modified in use so that they no longer meet the definition (e.g. dissolved or gel-like polymers) or those that are permanently incorporated into a solid matrix (e.g. paints and powders for additive manufacturing).

However, labelling, verification and reporting requirements are planned for the latter applications.

The EU Circular Economy Action Plan, published in 2020, follows on from the restriction proposal and will address, among others, microplastic releases from artificial turf pitches, taking into account an opinion from ECHA.

### 3.1.2 Cosmetics, detergents, care and cleaning products

With regard to intentionally added (primary) microplastics, which are the subject of ECHA's restriction proposal, the product area accounts for 15.4% cosmetics and 16.5% washing, cleaning and sanitising agents including waxes, corresponding to about 16,000 tonnes per year (ECHA 2019).

The emissions from the vast majority of applications in the cosmetics and washing, cleaning and sanitising agents sectors are fed to sewage treatment plants via wastewater treatment, where over 95 % of them are converted into sewage sludge. In Germany, more than 80 % of the sewage sludge is already incinerated today (Bertling et al. 2021b).

With regard to total microplastic emissions, the proportion attributable to cosmetic applications is estimated by the IKW association to be approx. 0.1 to 1.5 %. Solid particles are considered analogous to the ECHA restriction proposal. However, it is not yet clear how polymer dispersions, which are used in large quantities as opacifiers and film-forming agents, are to be evaluated, so that large differences in quantity may result. Polymer dispersions mostly consist of particles in the range of 50 to 700 nanometers. Against this background, the lower limit of particle size in the definition of microplastics is the subject of intensive discussions in regulatory processes and standardization exclusions.

BUND criticises the too narrow definition for microplastics and has therefore extended its own assessments to include dissolved and gel-like polymers. At the same time, the BUND provides a positive list for cosmetic products in which, according to its own assessment, neither microplastics nor synthetic polymers are contained (Friends of the Earth, BUND 2021). With regard to the total emissions for polymers from the cosmetics and washing, cleaning and sanitising agents sectors, BUND has (Bertling et al. 2018a) estimated the ratios of particulate to dissolved polymers for Germany according to the following Table 4 estimated.

| Area | Particulate Polymers | dissolved, gel-like polymers |
|---|---|---|
| Cosmetics | 922 | 23.700 |
| **washing, cleaning and sanitising agents** | 55 | 23.200 |

Table 4: Intentionally added quantities (t/a) of microplastics and dissolved and gel-like polymers in cosmetics and washing, cleaning and sanitising agents.

According to the German Cosmetic, Toiletry, Perfumery and Detergent Association (IKW), cosmetics manufacturers in Europe have already achieved a 97 % reduction in the use of microbeads in rinse-off cosmetics as part of a voluntary commitment. Toothpastes are considered free of microbeads and the elimination or replacement of polymeric opacifiers - if they are regulated as microplastics according to ECHA - is planned (Industrieverband Körperpflege- und Waschmittel e. V. IKW 2021).

BUND also sees the development in cosmetics as positive, as many manufacturers are increasingly dispensing with synthetic polymers in addition to reducing microplastics even without a corresponding extension of the restriction proposal. However, BUND also notes that after an interim decline, more new products containing microbeads are now being offered again.[9]

For microencapsulated perfume oils, which serve a more efficient use of perfume oils, there is still no substitute for the plastic shell. There are corresponding research activities here.

In particular for film-forming polymers, which are used in the area of leave-on cosmetics, e.g. for hair sprays or nail polishes, the restriction is considered socio-economically disproportionate by the IKW and refers to a predominantly intended disposal as solid waste. However, the extent to which this is feasible

9 https://www.bund.net/meere/mikroplastik/erfolg/, last access: 1.04.2021

for each application and is actually practiced is as yet unclear.

A study by (Global 2000 2019) shows that synthetic polymers are contained in about 40 % of all laundry detergents and about 8.5 % contain solid microplastics. Ökotest magazine tested 25 heavy-duty detergents, of which only four did not contain synthetic polymers (Ökotest 2019). If one restricts the consideration to particulate microplastics according to the ECHA definition, washing, cleaning and sanitising agents have only a small share in the total amount of microplastics released (Table 4). According to IKW, polyurethane microbeads for ceramic cooktop cleaning have now been replaced by aluminium oxide and ground stone fruit seeds (e.g. apricots).

With regard to soluble or nanoparticulate polymers, it is often argued that they are significantly less persistent compared to solid microplastics. Duis et al. (2021) have therefore compiled the environmental behaviour of three soluble polymer classes that are frequently used in cosmetics and washing, cleaning and sanitising agents in a review paper. Basically, the authors expect a high retention capacity in wastewater treatment plants through sorption and complexation with subsequent sedimentation. The downstream degradation in the sewage treatment plant has hardly been investigated so far, but previous findings indicate that it takes place rather slowly, so that an accumulation in sewage sludge and its application in agricultural soils cannot be excluded. For polyacrylic acids, they expect degradation rates of about 10 % per year. They consider the risk of bioaccumulation to be rather low due to the strong sorption tendency and high molecular weights. Whether this also applies to low molecular degradation products is not discussed. The ecotoxicological effects are polymer-specific, but according to the data available so far, especially under natural conditions, they are rather low. The authors mention, however, that the determination of realistic values for exposure, which is central to a risk assessment, is hardly feasible due to a lack of data. In particular, consumption data and knowledge of the distribution equilibria between liquid and solid phases are lacking.

The combination of a voluntary commitment with a downstream ban, as is to be expected in the cosmetics sector, could in principle represent an exemplary approach. In this way, industry can already test the effects of a waiver and thus identify opportunities, but also socio-economic risks, which can be introduced into the subsequent regulatory process.

Nevertheless, many companies and the industry associations still reject a ban and prefer voluntary self-commitment. However, the extent to which a long-term restriction to a voluntary commitment is also ideal from a competition perspective has not yet been investigated.

From the point of view of consumer protection, voluntary or compulsory product labelling, such as already exists in drugstore chains, is difficult for consumers to understand, as the labels created by manufacturers and retailers themselves contain non-standardised/certified terminology, in some cases have different requirements with regard to particulate and liquid/gel synthetic polymers, and also differ visually.

The inclusion of advanced criteria for synthetic and modified natural polymers in dissolved or gel form in the “Blue Angel” can also reduce the polymer loads in cosmetics, detergents, care products and cleaning agents in the medium term.

### 3.1.3 Artificial turf

Plastics play a major role in sports; above all, their cushioning properties, low density or adjustable permeability make them particularly interesting for many applications. At the same time, however, they are also associated with microplastic emissions. The release of textile fibres from sportswear, the abrasion on sports equipment or sports surfaces (artificial turf, tartan tracks, etc.) and, above all, the release of so-called performance infill from artificial turf, riding arenas or tennis courts are some examples. The latter consists of thermoplastic or elastomeric particles, is the subject of ECHA's restriction proposal and is primarily addressed in this chapter.

From the perspective of the German Olympic Sports Confederation (DOSB), microplastic emissions are one of many environmental impacts emanating from sports facilities. In terms of a holistic life cycle approach, other ecological effects and also the social benefits must be included in a holistic consideration. The DOSB sees concrete potential for reduction in structural measures (edging, containment systems), organisational measures (care and maintenance) and awareness-raising among planners, manufacturers, operators and users.

However, experimental studies on infill losses, transport pathways and sinks have hardly been conducted so far. The relevance of various influencing factors (location, intensity of use, retention measures, maintenance, etc.) has also been the subject of mainly theoretical considerations to date.

The DOSB points out that the structural design of pitches in Germany differs from abroad in terms of lower infill quantities. However, this is neither quantifiable nor is there any evidence that this leads to lower infill losses.

(Bertling et al. 2021a) investigated 15 artificial turf pitches in Switzerland and Germany in 2020, which were constructed according to the systems described in the German DIN 18035-7. The average infill loss per pitch was 2.7 tonnes per year. However, the values varied considerably. A correlation with the infill quantity, the age of the pitches or the intensity of use could not be established.

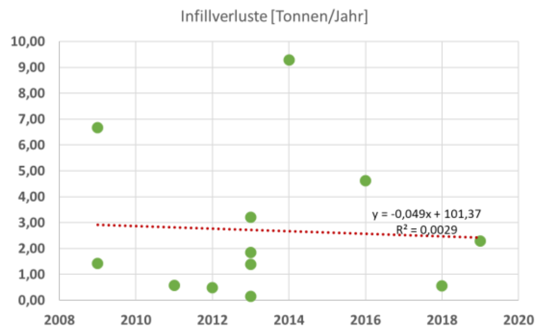


Figure 3: Infill losses of different artificial turf pitches with different year of construction (Bertling et al. 2021a)

It is unclear so far what the main discharge pathways for infill are. Possible discharge paths are:

- through drainage systems in water management
- through extreme weather events and playing in the vicinity of the pitches
- by adhering to people, sports shoes and clothing
- through care and maintenance activities
- through snow removal
- handling and storage of granules and
- losses during installation and dismantling

(Breitbarth et al. 2021) investigated the rainwater and wastewater drains at four sites. They determined that 0.3 to 14.5 kilograms per court per year reach the precipitation runoff and 34 to 53 kilograms per court per year reach the wastewater drain via the showers and changing rooms. In particular, the large quantity that apparently reaches the changing rooms and showers suggests that large quantities leave the site without entering the pitch drainage system.

Hann (2018) estimates the mass fraction of the released amount that ends up in soils and the wastewater system to be 45 %. The assumption made by the Danish Technology Institute (DTI) that artificial turf pitches compact and that a large part of the replenishment volume remains on the fields (Lokkegard et al. 2019) has not yet been confirmed in practice (Bertling et al. 2021a).

Due to the rather large particle size of 500 micrometres to 5 millimetres with a particle density of 1.2 to 1.7 grams per cubic centimetre, it is likely that large parts of the emitted infills remain in sewage sludge, soils and sediments and only small amounts are transferred to the oceans.

Options for solutions are discussed:

- natural grass
- alternative infill materials (sand, cork, olive pits, biodegradable PLA)
- unfilled seats
- retention measures (barriers, scrapers, cleaning systems, filters in the sewage system)
- fiber structures that require less infill or retain it

In a recent case study, it was shown that emissions to water bodies can be further reduced when comprehensive sets of measures are implemented (Regnell 2019). The potential reduction in losses to the wastewater system is reported from 15.5 to 0.1 kilograms per site per year. The greater part of this is fibre material (Regnell 2019). The extent to which such comprehensive measures can be implemented across the board and whether they are the more economically viable alternative to dispensing with or replacing infill still needs to be clarified.

### 3.1.4 Pellet Loss

Raw polymers, compounds (additive polymers), masterbatches (concentrates) and regranulates are offered in pellet form. Pellets are preformed bodies of a molding compound with largely uniform dimensions that are often used as starting material in extruders and injection molding machines. They are the most important form of supply for thermoplastics in many stages of the value chain. In addition, powders, grit, micro pellets and flakes are also used. In addition to these bulk types, semi-finished products such as sheets, pipes, etc. are also used. However, since thermoplastics are typically processed by melting and rarely by machining, semi-finished products play only a clearly subordinate role.

These pellet granules generally do not enter the environment through use, but through losses during production and transport between production and processing sites. Product stewardship measures are proposed to reduce these pellet losses:

- Raising awareness about plastic pellets among the actors in the plastics producing and processing industries
- Introduction of an accredited certification system with external audits
- Mass balances across value chains with a central compliance registry and/or blockchain technologies.
- Adaptation of management systems
  - Identification of hotspots
  - Set up monitoring systems
  - regular (internal) audits
- Procedures to reduce pellet losses during production
  - Regular sweeping up/vacuuming
  - Install covers, filters or strainers in wastewater collection systems
  - Avoidance of damage to bags and containers through more stable packaging materials and better handling systems (softtips for forklift trucks)
- Education and training of employees and awareness of responsibility
- Motivate customers and suppliers to also implement measures

Due to the global value chains in the plastics industry, it seems inevitable to incorporate the initiatives on pellet loss into a global standard. A corresponding standard must not only include plastics producers and processors but must also include distributors and transport companies. In addition, there are special applications of pellets as spacers for paving stones or as end products for consumer applications (modelling clay for masquerades), which may need to be assessed separately as part of ECHA's restriction proposal.

## 3.2 Microplastics through use/wear of products

### 3.2.1 Regulatory aspects

In addition to ECHA's proposed restriction on intentionally added microplastics, the European Commission also addresses unintentionally released microplastics in its plastics strategy. Policy options are to be examined for the product groups tyres, textiles and paints. For example, minimum requirements for tire design and information requirements (possibly for corresponding labeling obligations) as well as the development of standardized methods for assessing the loss of microplastics from textiles and tires are mentioned here. In addition, measures are to be defined to reduce the release of plastic granulates along the plastic supply chain. Furthermore, the consideration of microplastic separation and disposal aspects in the evaluation of the Urban Waste Water Directive (Directive (EEC) No. 91/271) is mentioned and the possibility of Extended Producer Responsibility schemes to cover costs incurred for necessary remedial actions is considered.

The Evaluation of Directive (EEC) No. 91/271 has been completed in the meantime. It was found to be insufficient or too old to take into account contaminants of emerging concern (CECs) such as pharmaceutical residues and microplastics, which have only recently come up for discussion. (European Commission 2020). At present, it does not contain any regulations that explicitly target the removal of microplastics from the wastewater stream. However, the evaluation explicitly states that, considering the societal costs and benefits, any measures following the evaluation should take into account the question of whether the scope of the Directive should be extended to take into account these “emerging pollutants” (European Commission 2019).

The action plan for the circular economy published in 2020 follows on from the considerations on the reduction of microplastics already made in the plastics strategy. The European Commission explicitly wants to reduce unintentionally released microplastics:

- Develop labelling, standardisation, certification and regulatory measures (including measures that address the removal of microplastics at all relevant stages of the product life cycle)
- Further develop and harmonise measurement methods, in particular for tyres and textiles
- Close knowledge gaps on quantities and risks of microplastics in the environment, in drinking water and foods

In addition, the initiative “Environmental pollution by microplastics - Measures to reduce the environmental impact” is currently in the preparatory phase. As part of the initiative, the European Commission is preparing a proposal for a regulation that is specifically intended to address and reduce microplastics that unintentionally enter the environment. The proposal will in particular address labelling, standardisation-, certification and regulatory measures for the main sources of inputs. The Commission is currently preparing a first impact assessment of this measure. Public consultations are planned for 2022..

### 3.2.2 Tire wear

Tire wear is the largest source of microplastics (Bertling et al. 2018b; Hann 2018). It is caused by friction between tyres and road, in particular by lateral forces during steering as well as slip during braking and acceleration. Tyre wear is usually present as an aggregate of rubber and road surface (Tire-Road-Wear-Particles, TRWP). The proportion of road wear is approx. 50 % (Wirtschaftsverband der deutschen Kautschukindustrie e. V. 2020).

Based on current knowledge, a released amount of 100,000 to 130,000 tonnes per year or 1.2 to 1.6 kilograms per capita per year seems realistic for Germany. Cars emit about 100 milligrams per kilometer, trucks about 900 milligrams per kilometer (Bertling et al. 2018b; Hann et al. 2018; Magnusson et al. 2016a).

When generated, tyre wear is either deposited on the road surface or emitted into the ambient air. However, the majority remains on the ground (Unice et al. 2019; Sieber et al. 2020; Verschoor et al. 2016). The deposited portion can be transported by wind, water, and traffic-related mechanical stresses and turbulence to the edge of the roadway or adjacent soils and into surface waters, as well as directly into marine ecosystems in close proximity to the roadway. Concentrations generally decrease with distance from the road, with roadside concentrations sometimes higher than on-road concentrations (Wagner et al. 2018).

It is estimated that about 40 to 50 % of tyre wear can enter the wastewater system directly or indirectly. At the same time, the concentration in sediments is significantly higher than in the water column, which is an indication of rather low mobility.

With regard to wear entering the sewage system, there are generally three possibilities:

- Wear that occurs in urban areas is fed into the sewer system via the road drainage system. In large cities and in the south of Germany, sewage and rainwater are discharged together in a combined sewer system. Here, a large part of the wear is discharged into sewage treatment plants. If, on the other hand, water management is based on a separate system, which is predominantly prevalent in younger urban areas, rural areas and tends to be more common in the north of Germany, the precipitation water and thus also the tyre wear is not routed to the sewage treatment plant, but instead flows directly into the watercourses (receiving waters) or, if available and appropriately maintained, into so-called relief structures such as rainwater overflows, rainwater overflow basins, storage sewers and rainwater retention basins.
- TRWP that originate outside of towns (or in areas that do not have a sewer system) are partly drained via ditches as part of a road drainage system. These ditches are either directly connected to watercourses or end in soakaways, seepage basins and sometimes in retention soil filters. The extent to which certain spillway structures lead to a separation of the TRWP has not yet been investigated in detail.
- In the event that TRWP enter a wastewater treatment plant through a combined sewer system, the majority is retained in the grit chamber due to its high density (≈ 1.8 $g/cm^3$ ). Grit is usually recycled (e.g. in road or landfill construction). If the organic content is too high, the sand is often washed. The washing water and thus also the washed-out organic matter are then returned to the sewage treatment plant. TRWP that do not remain in the grit are therefore also transferred to the sewage sludge. At the clear outlet of the sewage treatment plant, only little TRWP is to be expected quantitatively. However, fine particles in particular could be discharged here (Unice et al. 2019).

When sewage sludge is recycled on agricultural land, there is a possibility that TRWPs contained in the sewage sludge may be released from fields into streams and then further into marine ecosystems.

Of particular importance with regard to the transport of TRWP are the so-called combined sewer discounts in the presence of a combined sewer system. During heavy rainfall, the wastewater load can exceed the capacity of the wastewater treatment plant. In these cases, wastewater is discharged directly and untreated into water to relieve the system. Since heavy rainfall can also cause large loads of dirt to be remobilised on the roads, this can lead to increased transport of tyre wear.

In general, however, even if TRWPs are discharged directly into watercourses via the segregation system, combined sewer overflows or the clear effluent of the wastewater treatment plant, large parts remain in the sediments of rivers and at the bottom of canals. The density of TRWP is significantly higher than that of water, so that transport takes place by slow rolling and jumping movements (saltation) or bed movement of sediments rather than by swimming.

For this reason, it can be assumed that only a small proportion reaches the marine ecosystem. Unice et al. (2019) estimate in their study, using the Seine as an example, that the proportion reaching the oceans is less than 2 %. Baensch-Baltruschat et al. (2021) estimate the share at 0.2 %. For Germany, this means an emission to marine ecosystems of about 250 to 2,500 tonnes per year.

In the case of solution options for the reduction of TRWP, a distinction must be made between solutions that already reduce the generation and those that retain TRWP that have been generated.

Simple measures include, in particular, the correct adjustment and maintenance of vehicle components. This includes the correct alignment and balancing of wheels as well as wheel alignment, maintaining the correct tyre pressure and changing between summer and winter tyres and storing them adequately (Verschoor et al. 2016).

In terms of tyre product design, Verschoor et al. (2016) recommend more wear-resistant tyres with a longer mileage. Even though tyre manufacturers regularly justify wear as necessary for tyre grip, evaluations of ADAC tests show (ADAC 2019) for example, show that grip and mileage do not correlate strictly (see Figure 4). Even if mileage does not strictly correspond to wear - tread and uniformity of wear still play a role here - it gives a good indication of mass loss. Consequently, there might be a need and -potential for optimization here.

Tires with silica as a filler instead of the commonly used carbon black, for example, are said to be less susceptible to wear (see (OECD 2014). Furthermore, Verschoor et al. (2016) recommend using tyres that are more resistant to degradation by UV light, moisture and oxygen.

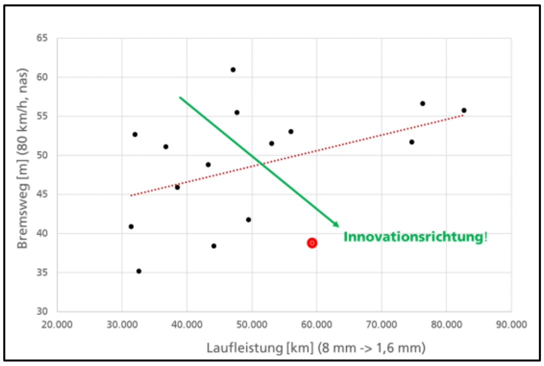


Figure 4: Relationship between mileage and wet grip for summer tires 215/65 R16, red dot = “best in class” (Fraunhofer UMSICHT, based on data from (ADAC 2019) ).

In principle, it should be noted that reducing the distance driven is the most effective means of avoiding tyre wear (Jepsen et al. 2019; Verschoor et al. 2016). Starting points here are traffic-avoiding settlement and traffic planning as well as the promotion of more environmentally friendly modes of transport (Rodt et al. 2010).

High speeds and thus individual driving behaviour, stop-and-go traffic and turns favour wear (Figure 5). This suggests that speed limits in particular could reduce tyre wear in built-up areas (Blömer et al. 2020; Jepsen et al. 2019; Verschoor et al. 2016).

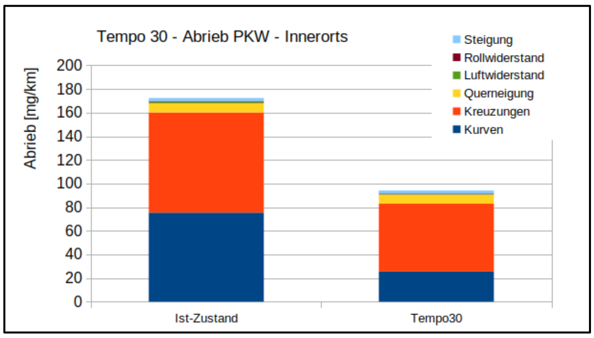


Figure 5: Effect of lowering the speed limit in built-up areas from 50 to 30 km/h on tyre wear (Blömer et al. 2020)

The nature of the road surface also influences wear and the distribution of particles on the road. Road surfaces could be optimised to reduce friction between the tyre and the road and/or prevent the distribution of wear on the road. Timely maintenance of roads can also help reduce wear (Verschoor et al. 2016).

Retention measures include improved street cleaning, which is mechanically or organisationally more geared towards microplastics, or the development of easier-to-clean road (surfaces).

The use of spillways (rainwater overflow basins, storage channels, etc.) for rainwater drainage is particularly important from the perspective of marine protection. Periodic inspections and cleaning of channels as well as the disposal of sediments and deposits are necessary to prevent the re-mobilisation of deposited microplastic particles (Baensch-Baltruschat et al. 2021).

Even if the clear outlet from wastewater treatment plants is probably not a particularly relevant input pathway for tyres into the oceans, additional treatment stages, which have already been implemented in some cases, can increase the removal rates to over 98 % (Fuhrmann 2019; Sieber et al. 2020; cf. also Chapter 3.4). Conceivable processes are cloth filtration, microscreening, sand filters and membrane plants.

With regard to combined sewer overflows, the wastewater system must be optimised and adequately dimensioned in order to reduce overflows. Additional structural measures such as rainwater retention basins and rainwater overflow basins can also counteract the need for combined sewer overflows.

### 3.2.3 Road markings

According to one market participant, between 23,000 and 27,000 tonnes of road markings are sold in Germany each year, of which 33 % are cold plastics, 13 % cold spray plastics, 33 % thermoplastics and 21 % water-based high-solids dispersions.[10] It can be assumed that the mass sold roughly corresponds to the mass applied to the roads each year.

Microplastic emissions are caused by mechanical, chemical and weather-related influences. Experimental data on which factors influence the formation and spread of microplastics from road markings and to what extent do not yet exist. Since the markings on heavily trafficked roads have to be renewed more frequently than on roads with less traffic due to higher wear, a correlation between the intensity of traffic and the abrasion of the markings can be assumed.

The layer thickness of the markings is brought to the same constant level with each renewal. In the case of cold, cold spray and thermoplastic markings, the residues of the old marking are removed by high-pressure water cleaning before the new marking is applied. The mass of removed road marking amounts to approx. 7,000 tons per year. Plastic emissions caused by road markings can therefore be estimated at about 180 to 240 grams per capita per year (16,000 to 20,000 tons per year). Eunomia estimates the quantities released per capita for Europe[11] at 184 and the European Council of the Paint, Printing Ink and Artists' Colours Industry (CEPE) at 214 grams per year (CEPE 2018; Hann et al. 2018). Older studies estimate microplastic emissions to be somewhat lower, at 20 to 120 grams per person per year (Lassen et al. 2015b; Magnusson et al. 2016a; Sundt et al. 2014).

A fundamental question is whether the losses can be fully counted as microplastic emissions. Oxidation of the polymeric binder is known to lead to layer thickness reductions of 1 to 15 micrometers per year (Technical Information Centre of the German Painting and Varnishing Trade - Stuttgart 1992).

However, the extent to which coating mass loss occurs through chemical decomposition or fragmentation is largely unknown. The CEPE council estimates the proportion lost through complete chemical degradation at 36 to 50 % of the initial mass.

Some market participants in the field of road markings consider the loss accounted for above to be too high. According to their studies, some of the road markings remain on the road and are not completely rubbed off, which means that the emissions are lower (Burghardt et al. 2020). However, what happens to these markings remaining on the roads in the long term is not explained.

The proportion of polymer mass in road markings is between 10 and 40 %. Chalk and titanium are the main fillers used, while glass beads are used as a dispersing agent in dispersions. Polyacrylates, epoxy and melamine resins as well as thermoplastic hydrocarbon resins are used. The density of the markings is greater than that of water, so that abraded particles sediment easily.

Approximately 75 % of the markings are placed out of town and 25 % in town (CEPE 2018). It is not known how much of the abrasion ends up directly in the sewage system or on the road or in adjacent green spaces. The quantities remaining on the road are also removed in part (at least in urban areas) during street cleaning. Particularly in the case of markings on motorways, it is likely that emissions are not recovered by cleaning operations and do not enter the wastewater system.

Abrasion that occurs within towns and cities can be fed into the sewage system via the road drainage system. In large cities and especially in southern Germany, where wastewater and rainwater are discharged together (combined sewer system), large parts are likely to end up in the sewage treatment plant.

Further, the transport is likely to be very similar to that of tire road wear particles, as the point of generation is almost identical and in many cases composite particles from both emission sources could also result. It is generally expected that the majority will remain in the road shoulders and surrounding soils, with only a small proportion entering the marine environment (CEPE 2018).

Solution options to reduce the release could be:

- Preferred recommendation of low-wear variants in the application (2K systems) and provision of

[10] Personal information Mr. Guder, Swarco.

[11] EU 27 + CBR, SUI, NOR, TUR.

the corresponding product information on wear resistance
- Only de-labelling techniques that have been proven to prevent release (suction methods) should be used.

In principle, road markings are an important component of roads that can hardly be dispensed with in terms of road safety. All solution options would have to take this circumstance into account.

### 3.2.4 Colours - architectural paints and vehicles

A total of approximately 2 million tons of paint were produced in Germany in 2020 (VdL 2021). Paints consist of about 20 to 40 % additives, pigments and fillers as well as polymer binders. The finished paints are used as surface coatings in numerous applications. During drying, the solvent evaporates and additives, fillers, pigments and polymeric binders remain on the surface. The polymer content of the dry layer can vary over a wide range.

Paints and varnishes contain primary microplastics in their as-delivered state, which are intentionally added to the products. In particular, it can be released during cleaning of the paint containers and brushes. This release is subject to ECHA's restriction proposal and, strictly speaking, would need to be addressed in Chapter 3.1. Applied and bound paint, on the other hand, falls outside the scope of regulation, but is addressed in the European Union's plastics strategy.

According to the ECHA definition, a particle is a microplastic as soon as it contains more than 1 % polymers. Therefore, in the case of secondary microplastics, the total mass of the emissions and not only the binder content should be accounted for. This is particularly recommended since in many cases negative environmental effects are to be expected from the additives in particular.

In the field of environmentally friendly applications, vehicle coatings, facade and architectural paints are of particular importance.

The reasons for the limited resistance are the photolytic, hydrolytic and chemical degradation of the binder, which leads to a loss of adhesion as well as to the exposure of pigments and fillers, which can then be removed by light mechanical stress. There are indications that appreciable proportions of the polymer are already degraded during the use phase. Further investigations are currently being carried out in this regard.

In addition, changes to the substrate can also lead to paint release in the form of spalling or peeling, particularly due to the rusting of metal substrates, swelling and the attack of microorganisms and fungi on wooden substrates. In order to counteract these effects, the galvanisation of metal substrates and the biocide treatment of wood have been established in addition to constructive measures. A comparative evaluation of the environmental effects of galvanization, biocide use and plastic emissions is not yet available.

Total emissions from paints and varnishes (excluding road markings) in Europe are estimated by the CEPE counsil to be around 32 grams per capita per year. Other sources for Scandinavian countries give a range of 15 to 83 grams per capita per year (Lassen 2015; Magnusson et al. 2017; Sundt et al. 2014). Thus, paints and varnishes are among the significant sources of microplastic emissions in terms of the amount released. However, estimates to date are based on little experimental data, which are also subject to large uncertainties. Particle sizes can vary from the millimetre to the micro- and nanometre range (see Figure 4).

Coating systems for vehicles have been significantly optimized in recent decades. Today, the substrates are designed to be largely corrosion-resistant, the paints have good adhesion, are UV- and chemical-resistant and abrasion-resistant. Emissions are estimated at less than 100 tonnes per year in the EU (approx. 0.2 grams per capita per year) (CEPE 2018).

In the field of architectural coatings and plasters, around 950,000 tonnes were produced in Germany in 2019, of which around 25 to 30 % were for exterior applications. With a dry content of 20 to 40 % for polymers, pigments, fillers and additives, the total dry mass applied in exterior applications in Germany is in the range of about 45,000 to 115,000 tons per year. The usual service life (durability) is 15 years (average building life > 80 years). Apart from pure silicate paints, which have only been used to a limited extent to date for economic and application reasons, all paint systems have polymeric binder components. These can vary from 20 to 95 (CEPE 2018). Ultimately, however, the polymeric binder content is insignificant according to the microplastic definition. It is estimated that just under 2.5 to 5 % of paints and varnishes enter the environment as microplastics through the effects of wear. A further 0 to 5 % are emitted through deliberate removal measures such as sanding, scraping and scratching (Verschoor et al. 2016, CEPE 2018). The release for Germany is estimated to be around

1,125 to 11,500 tonnes per year (14 to 140 grams per capita per year).

An estimated 57 % of the abrasion from architectural paints is emitted into/onto the soil. The further dispersion from there has not yet been investigated. Approx. 40 % of the remaining abrasion enters the sewer system and is thus fed into the sewage system. The remainder, approx. 3 %, enters water bodies directly (Verschoor et al. 2016). In view of the sometimes very small particle sizes, dispersion as dust via the air is also probable. In a 2019 study, the Alfred Wegener Institute demonstrated the existence of microplastic particles in the Arctic. The most common particles found were polymers such as those used in paints and varnishes. Bergmann et al. (2019) concluded that a large proportion of the microplastics found came from abrasion of coatings, primarily facade paints, and had reached the Arctic through atmospheric transport.

Measures to reduce inputs are required above all in the area of architectural paints. Sensible solution options would be:

- Consistency should be further increased
- The development of purely mineral paints (e.g. pure silicate paints) should be promoted, provided that they do not have a worse overall ecological balance.
- Systems for restraint during maintenance and grinding operations should be developed
- Where paint emissions cannot be avoided, all ingredients should be ecotoxicologically safe and sufficiently rapidly degradable to avoid high accumulation in the environment.

### 3.2.5 Ship coatings

Commercial shipping without corrosion-reducing and fouling-reducing coatings is hardly conceivable today. Extended durability and reduced fouling also have a positive ecological effect via lower energy consumption of the ships. Nevertheless, there are also practices in the recreational shipping sector that dispense with coatings altogether.

Approximately 700,000 tonnes of marine paint (underwater and superstructure) are used globally per year in total in commercial shipping, recreational shipping, marine and pontoon applications (Biocide Information Limited 2017; Watermann and Herlyn 2020). Basically, a distinction can be made between durable abrasion-resistant hard coatings and eroding and self-polishing antifouling coatings. The latter are water-soluble. The polymers used for hard coatings are mainly epoxy resins, chlorinated rubber and vinyl compounds, to which glass fibres, glass beads or aluminium powder are often added to increase abrasion resistance. For water-soluble eroding coatings, rosin resins, methyl methacrylates, and silyl acrylates are used. Polytetrafluoroethylene (PTFE) is also used as a friction reducer, and polydimethylsiloxanes or silicone oils as anti-adhesive agents.

Releases occur both from shipping itself and from inadequate retention during repair. Inputs to the world's oceans from eroding water-soluble coatings are estimated to be around 80,000 tonnes per year (of which around 20-30% is polymeric binder) (Biocide Information Limited 2017; Watermann and Herlyn 2020). The majority is likely to end up and remain directly in the waters. The abrasion of marine coatings also releases biocides, with which most marine coatings are equipped.

Measures to be considered include avoidance options through design devices and improvement of the coatings themselves, both to minimise losses to shipping and to improve retention during repair. Specifically, possible solution options are:

- Use of constructive devices such as oversized fenders (cruising) or circumferential protective strips (ferries). Increased use of hard coatings instead of self-polishing antifouling coatings (especially in the area of high mechanical stress such as in the changing water area of ships, flat bottoms of ships with near-bottom operations such as in the Wadden Sea or rivers, or ships operating predictably in ice areas)
- In recreational boating, use of abrasion-resistant, biocide-free hard coatings in conjunction with cleaning, e.g. in floating facilities with collection devices (example Sweden)
- Increased use of biocide-free coatings, e.g. foul release coatings, film systems, fibre coatings
- Development of fully degradable and ecotoxicologically safe coatings for eroding and self-polishing coatings; more frequent and early cleaning to avoid fouling and corrosion
- Removal and application of the paint layers, if possible in closed systems
- No dry blasting
- Equipping of washing areas (also in marinas) with an efficient catchment system, settling and filtering technology
- Underwater cleaning should only be carried out on particularly abrasion-resistant hard coatings
- Add instructions for private boat owners on maintenance and paint removal to the product information.

Shipyards:

- Dry blasting only below the dock edge and in enclosed areas
- Collect water from ultrahigh-pressure blasting and clean it in appropriately equipped facilities.
- Steel shot blasting only in closed rooms
- Application of paints by spraying primarily in enclosed spaces, otherwise only below the dock edge using “paint nets” and observing the wind force, rolling method if necessary
- Testing of new processes for ink application

### 3.2.6 Building materials

Foamed plastics (in particular expanded polystyrene,EPS, and polyurethane foams, PU) are of great relevance with regard to microplastic emissions from the construction industry. They fragment very easily and have a low density, which gives them a high mobility. Particle foams of polystyrene in particular break very easily. Storage of virgin and waste materials often takes place openly in the environment in the construction sector. Small-particle waste also accumulates during processing or particles are emitted directly (e.g. during the processing of lightweight screed). In particular, the cutting of foams with mechanical knives causes large particle emissions.

Investigations at construction sites revealed direct inputs into road gullies of 0.06 % of the processed polystyrene foam (inputs exclusively from drifting, no inputs from precipitation runoff). With the total processed quantity in Germany of approx. 12 million cubic metres, this corresponds to about 6,700 cubic metres. Due to the low density of the plastic foams, the mass is only about 100 to 150 tons. Since we are only dealing here with the direct inputs, the total loss in the processing of polymeric insulating materials is probably many times highe (Breitbarth 2019).

Of the large microplastics (1 to 5 millimetres) identified in rivers, polystyrene beads have a mass fraction of about 7 to 47 %. In terms of particle numbers, the dominance is even more pronounced due to the low density. In terms of particle numbers, the proportion is 85 to 96 % (Breitbarth 2017). The low density also means that the particles are easily blown away and float well, so that the transition into the sea is favoured in contrast to heavy sedimenting particles.

The losses are mainly caused by the processing methods and inadequate storage. Furthermore, composite thermal insulation systems are glued, directly plastered and reinforced according to the current state of the art. During dismantling, the release of large quantities of microplastics is very likely. In the medium term, the development of alternative insulation materials (giving up particle foams) would be a sensible way forward. In addition, the deconstruction or disposal of polymeric insulation materials should already be considered today.

Resolution strategies may include:

- Zero-loss strategies for polystyrene foam applications analogous to the Zero Pellet Loss Strategy of the plastics industry
- Use of filter systems in the area of construction sites, especially during the construction phases (e.g. filters for sewage shafts)
- Requirements for material security (storage in closed containers)
- Avoidance of certain processing methods (hot wire instead of knife)
- Extension of the Construction Products Regulation to include application and processing requirements that have an effect on reducing emissions.
- Instructions for processing on the product sheets
- Development and use of alternative insulation materials

### 3.2.7 Textiles

The global production of man-made fibers was about 80.5 million tons in 2019. Their share in total production is over 75%. In the field of technical textiles, the share of man-made fibers is significantly higher than in apparel. The most important group of fabrics in man-made fibers is polyester fibers (PET), the annual production volume is about 48.3 million tons (about 60%) (ICV 2020). Other important fabric groups are polyamides, polyacrylic and modified cellulose. [12]

Microplastic emissions occur during the washing, drying, use and wearing of clothing. Studies on textile fibres in wastewater in sewage treatment plants showed proportions of 67 % for polyester and 17 % for polyamides (Carney Almroth et al. 2018).

[12] In the case of cellulose fibres, it is debatable whether they should be considered as natural or semi-synthetic fibres.

(Spiess 2019) estimates the proportion of microplastics in the form of fibres and particles in soil-related house dust at approx. 85 % on the basis of microscopy analyses. The plastic phase consists predominantly of PET and polyurethanes. Clothing, upholstery and shoe wear are suspected sources.

(Cai et al. 2020a; Cai et al. 2020b) analysed microplastic emissions from various polyester fabrics with regard to the manufacturing process. They found that the microplastic fibres are largely produced during the manufacturing process, but remain in the fabric. Initial studies have already been carried out on emissions from use and wear, but no estimates have yet been made of the quantities released (Dris et al. 2016b).

When textiles are washed, fibres are mobilised, whereupon they are released into the wastewater. In addition, microplastic fibres can also be generated and released by the mechanical and chemical stress in the washing machine (Dalla Fontana et al. 2020). Numerous scientific studies exist on fibre losses during washing and drying, which are sometimes difficult to compare with each other due to different framework conditions and varying test parameters.

According to results from (Pirc et al. 2016) new garments release about 10 to 25 times more fibres during washing than the same garments in the tenth wash cycle or in subsequent wash cycles. However, it is unclear how it behaves towards the end of a garment's life. It would be possible that older clothing that is frayed or already has holes, in turn, releases increasingly more fibres per wash. However, the various studies do not make any statements on this, as no study involved so many washings.

It is also unclear how often which type of clothing is actually washed in reality. Sports clothing consists almost exclusively of polyester or other synthetic fibres and is presumably washed much more frequently than jackets, for example, especially by people who are active in sports. The greatest release is expected from fleece clothing (Carney Almroth et al. 2018).

As an average value from all the experimental studies described in the literature, an average fibre loss for washing of 194 milligrams per kilogram of washed textiles is obtained. So far, microfibres have not been retained during washing, so that they are directly discharged into the wastewater (Blömer 2019).

(Pirc et al. 2016) state that on average three times more fibres are released when drying laundry in a tumble dryer than during washing. A mass loss of approximately 600 milligrams per kilogram is therefore realistic for drying. Most of the fibres are retained by the lint filter, the contents of which should be disposed of in household waste and not in waste water. It is therefore assumed that only 5% of the fibres are actually released as microplastics.

The annual microplastic emissions from washing and drying can be estimated at approx. 2,270 tonnes for Germany, or approx. 27 grams per capita and year (Blömer 2019). Other studies estimate microplastic emissions from fibre wear during washing and drying at between 1 and 226 grams per person per year (Essel et al. 2015a; Magnusson et al. 2016b; Sundt et al. 2014).

It can be assumed that most of the fibres end up in the wastewater. Exceptions could be made for textiles used outdoors. Sunshades, windbreaks, etc., which are often used for a very long time until the onset of clearly visible weathering, are relevant sources. Fibres from these products could be transported directly into water bodies, especially by rainwater drainage in the separation system or direct inputs via drifts.

Due to the lower density of synthetic fibres compared to mineral materials, it can be assumed that some of the fibres are separated from the wastewater during flotation or in the grease separator in the sewage treatment plant. The separated fibres are transferred to the digestion tower and then to the sewage sludge. Since man-made fibres have a higher density than water, most of them will also sediment in the grit chamber of the wastewater treatment plants. Provided that washing of the grit takes place to reduce the proportion of organics in the grit, the synthetic fibres are also likely to be resuspended and returned to the treatment process.

Studies by the University of Osnabrück assume a separation efficiency of 98 % in wastewater treatment plants (Carney Almroth et al. 2018). However, other studies indicate a significantly lower removal efficiency of 65 to 90 %. Significant degradation will not take place within the short retention time in the sewage treatment plant. Smaller fibres in particular could pass through the wastewater treatment plants. With a non-separated quantity of 2 to 35 %, the quantity assumed above would mean approx. 45 to 800 tonnes per year entering German watercourses. (Eunomia 2016) estimate much higher amounts in their study and give the global microplastic emissions that enter the oceans per year as 190,000 tonnes. (Boucher and Damien 2017) state in their study that textiles account for 35 % of total inputs into the oceans (tyre wear 28 %). Whether the assumption of a significantly higher transfer factor for textiles can be confirmed experimentally is still unclear. Apparently, however, many scientists assume that the shape and small size of the fibres make deposition more difficult and favour transfer to the oceans compared to other sources.

Opportunities for reducing the release of microplastics by textiles can be divided into those that reduce their formation, in analogy to the situation with tyres:

- No synthetic fibres
- Development of textiles with lower release through better weaving technology or finishing
- Gentler washing processes

and those suitable for retention:

- Pre-wash clothes industrially or pre-dry them at home in order to separate loose fibres specifically
- Washing machine filters, strainers or hydrocyclones
- Filters for the laundry (filter bags and fibre collectors)
- Filter for house dust during wet mopping (bucket filter)
- Improvement of separation technology in wastewater treatment plants

In terms of regulation, France was the first country in the world to decide on the mandatory installation of washing machine filters from 2025 and is trying to initiate corresponding regulations at EU level.[13]

For the evaluation of the different options, it is important that no conflicts of objectives arise. In particular, the resources required and the associated emissions for a retention technology must be in reasonable proportion to the reduction in emissions. Furthermore, it would also have to be clarified how toxic and persistently released textile fibres are in comparison with other emission types (e.g. tyre wear). However, not only the pure polymer fibres should be taken into account, but also the textile chemicals used, which facilitate processing and improve performance (textile refinement, finishing).

In the case of fibres, there is also a risk of lung irritation. For this reason, there may be a need for action under occupational health and safety legislation to reduce airborne fibre content, particularly in textile production.

## 3.3 Excursus I: Solution option biodegradable polymers

In the natural environment, microorganisms play an essential role in the degradation of organic substances. The so-called destruents ensure that the biomasses that accumulate annually in large quantities in polymeric form, mainly as lignocelluloses, are degraded and mineralized to low-molecular end products such as carbon dioxide or methane and water. In addition, new biomass is produced by growth and multiplication. This degradation is greatly accelerated by enzymes secreted by microorganisms. The rate of degradation depends strongly on the environmental conditions of temperature, humidity, oxygen availability and biological activity.

Synthetic polymers can also be degraded microbiologically if the chemical structure of the polymer chains permits either an environmental chemical (hydrolysis, oxidation, photolysis) and/or an enzymatic degradation of the macromolecules. This is necessary because microorganisms can usually only take up low-molecular substances as food into their cell interior. For accelerated biodegradation, the polymer chains must be structured in such a way that an enzymatic attack can cleave them. The speed of degradation is mainly influenced by the following factors:

- Number of microorganisms and composition of the microbial population
- Abiotic environmental conditions such as water availability, temperature, pH, oxygen and nutrient content
- Properties of the polymeric substrate, such as size and shape of the particles

Test procedures have been developed to simulate natural environments such as freshwater, seawater, soil, compost, etc. and have been laid down in standards (ISO, CEN, ASTM, DIN, etc.). These degradation tests are carried out under laboratory conditions so that the test parameters can be controlled and the degradation products quantitatively detected. The transfer of the test results to biotechnological production processes (e.g. composting) or especially the comparison with processes in the real environment is not always easy. For example, a product with certified industrial compostability may not be completely degraded after passing through an industrial composting plant and, for example, film residues may still be found in the compost. This is mainly dependent on the treatment

[13] https://www.oceanclean-wash.org/2020/02/france-is-leading-the-fight-against-plastic-microfibers/, last accessed 1,904,2021.

conditions in the composting plant (temperatures, residence times).

Standard specifications are currently lacking for testing degradation in the sea, but some are currently under development (ISO 22404:2019 - Plastic degradation in eulittoral zones; ISO/DIS 19679 Degradation at the seawater/sediment transition; ISO/CD 23977-2 Degradation in seawater). The different environmental conditions of the marine ecosystem are addressed. There is a tendency to test at lower temperatures with longer incubation times (comparable to testing degradation in soil over 24 months) (Table 5). In addition to degradation tests, ecotoxicological effects tests are also required. Laboratory tests have shown ecotoxicological safety for several polymers potentially degradable in marine waters (Schlegel 2019). However, the standardisation of these methods is still pending. Marine degradation tests are also subject to the fact that they can ensure intrinsic (in principle) degradability under the test conditions, but not actual degradation in every real marine environment. In principle, a combination of standardized test in the laboratory, tank test (ISO/CD 23832, currently under development) and field test (ISO 22766, under development) is appropriate to test a comprehensive analysis of biodegradability in the marine environment. One challenge in developing suitable tests is the long measurement times during which the microbiocoenosis must be kept alive (Weber 2019).

| Criterion | Industrial compost | Sea |
|---|---|---|
| **Temperature** | 60-70 °C | 0-30 °C |
| **Oxygen** | aerobic | aerobic, intermittent, anaerobic |
| **Nutrients** | sufficient | limited, excessive |

Table 5: Comparison of conditions in industrial compost and in the sea.

Biodegradable plastics have not been developed to be discarded into the environment, but mostly with a view to orderly disposal through industrial composting. Due to the significantly different environmental conditions, compostable materials cannot be expected to degrade in the environment after a few weeks or months. However, initial research results show that degradation of these materials also occurs in the range of years in natural environments, which is not observed for polyolefins (Napper and Thompson 2019).

Even if the degradation of compostable plastics in the environment may take significantly longer than under composting conditions, depending on the material and environmental conditions, the question of acceptable degradation time has not yet been answered. Ultimately, the aim would have to be to ensure that unavoidable emissions degrade so quickly that critical threshold values for environmental concentrations are not exceeded. Assuming that critical environmental concentrations have already been reached today, one possible approach would be that in future the quantity emitted per year and the quantity removed per year should be at most identical. (Bertling et al. 2018b).

For some products, such as certified compostable biowaste collection bags, which can increase the collection quantity and quality of biowaste, composting is a sustainable solution, provided that local composting and collection conditions are compatible with the collection bags used. In the agricultural sector, for example, mulch films certified as degradable on and in the soil can help avoid the environmental impact of fragments of non-degradable plastic films (Burgstaller et al. 2018). Other applications that are particularly often carelessly disposed of in the marine environment and for which biodegradable solutions would therefore be useful include cigarette butts, wet wipes or even specific applications such as zip closures for oyster bags.

Otherwise, the aim for all plastics, including biobased or optionally compostable ones, is material recycling or at least energy recovery. Recycling offers significant ecological advantages over composting. Biodegradable plastics end up in the residual plastics fraction in the standard recycling process at reprocessing facilities. Occasionally, if they end up in other fractions such as the polyolefin films, they are interpreted as interfering material. However, there are studies that show that even a few percent of these materials in the other recyclate fractions do not adversely affect their qualities (FNR 2017; Molenveld 2017). The fact that sorting and processing bioplastics is possible in principle was shown in a joint research project. Nevertheless, further research is necessary in order to develop functional plastics with good biodegradability and at the same time high recyclability (Hiebel et al.).

In principle, it is important that biodegradability neither has a negative impact on collection and recycling nor increases littering. Ultimately, biodegradability should only be identified as a product property in end consumer communication in exceptional cases. It should instead be a kind of emergency property in the case of unavoidable and unavoidable plastic emissions (Bertling et al. 2018b). In this sense, it represents an important option for overcoming the current situation with the majority use of hardly degradable polyolefins.

## 3.4 Excursus II: Solution options in water management

In water management, a distinction is made between wastewater and rainwater. There are regions in which the two types of wastewater are managed and treated separately and others in which they are combined as mixed water and treated together. Separation systems dominate in the north of Germany and in rural areas. The combined system is found increasingly in southern Germany and in densely populated large cities.

Microplastics can enter both types of wastewater. There is a tendency for microplastics from weathering and abrasion to be found primarily in precipitation and combined sewage, as they are mainly released outdoors. In contrast, much intentionally added microplastic is found in wastewater (cosmetics, paint residues, etc.). However, there are also many exceptions here, such as the infill of artificial turf pitches or coated seeds and fertilizers, which should be found primarily in precipitation and mixed water. The latter, however, are more relevant to the terrestrial than the marine environment, or the transition from the terrestrial to the aquatic environment through erosive processes is still little studied.

Microplastics in wastewater are largely transferred to sewage sludge. Some of the sewage sludge is used for agricultural purposes, i.e. spread on arable land as fertiliser (< 20 %). The greater part is used for energy recovery. Microplastics in mixed water are also mainly found in sewage sludge. However, during heavy rainfall events, there is a risk that the wastewater treatment plant will be overwhelmed by the water masses and that wastewater will enter natural waters untreated through so-called combined sewer overflow.

In the separate system, the separation of microplastics from the precipitation water is significantly lower, since here there is no equivalent treatment as within the sewage treatment plant. Nevertheless, some separation can be achieved through soil filters and other sedimentation systems. However, the majority of precipitation water does not receive adequate treatment.

In **Fehler! Verweisquelle konnte nicht gefunden werden.** the inflows to the natural water bodies are shown. It is clear that the untreated or poorly treated inflows from combined sewer overflows, rainwater discharge and direct runoff from road drainage are similar in size to the inflows from wastewater treatment plants. Rainwater drainage should therefore be given special consideration with regard to the microplastics problem.

Full treatment of precipitation water in wastewater treatment plants in order to achieve improved separation does not make sense, as these are not designed for the capacities required for this. The overall treatment performance would therefore drop significantly, so there is no advantage from an environmental point of view.

An overall schematic representation of microplastic pathways through the wastewater system are shown in Figure 7.

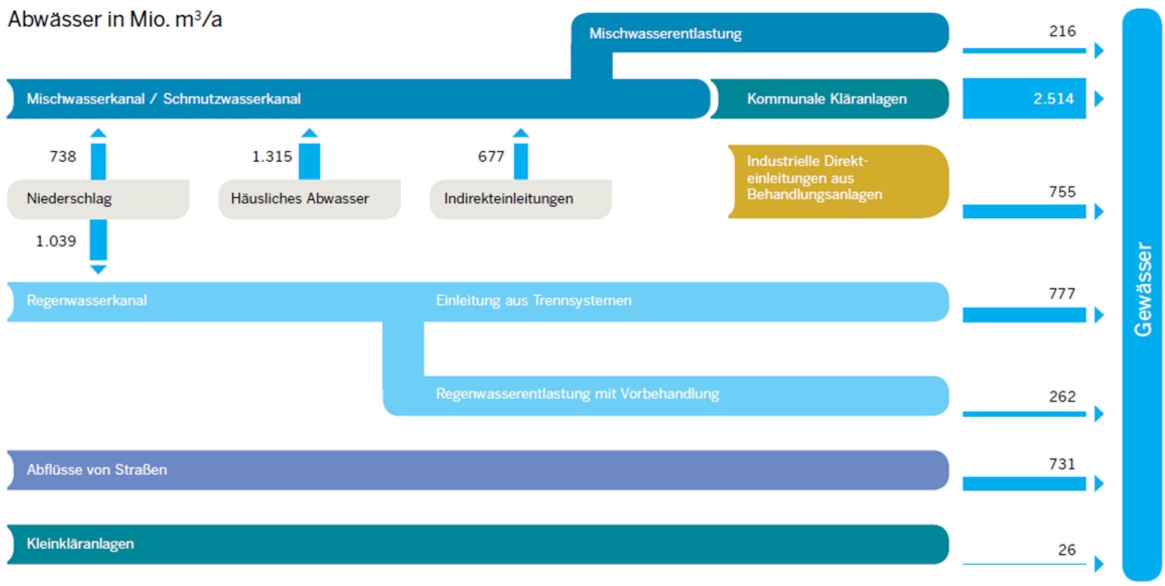


Figure 6: Wastewater inflows into natural waters (Sommer 2019).

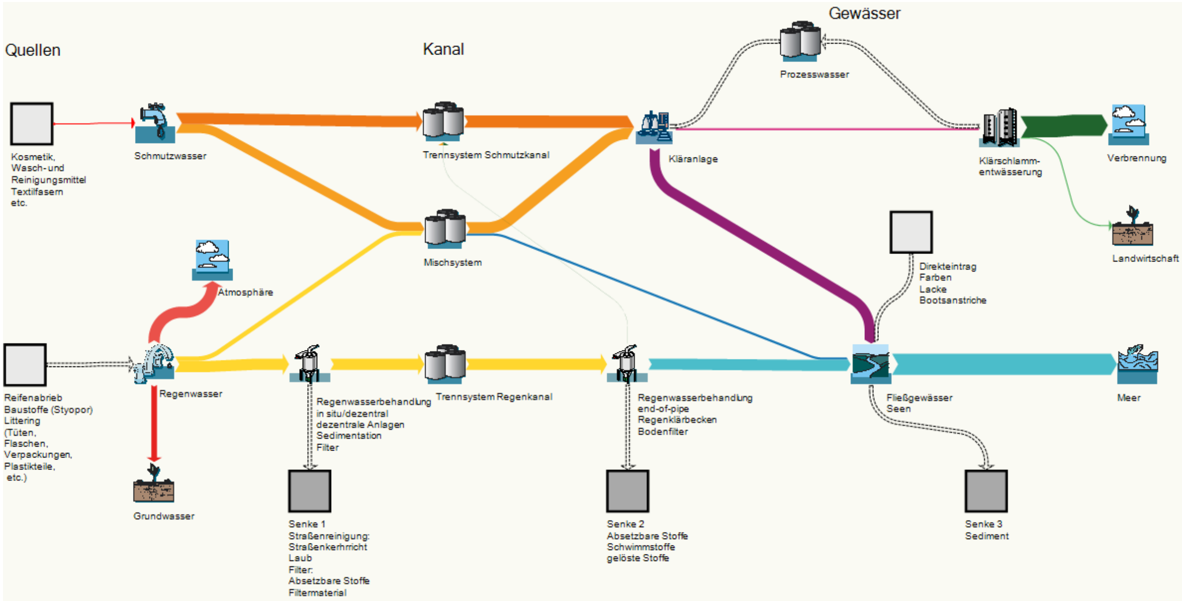


Figure 7: Qualitative representation of the transport pathways via the wastewater system. (Sommer 2019).

In wastewater treatment plants, plastic emissions are separated via the screenings, the grit slurry material or the sewage sludge. Macroplastics are mainly found in the screenings, and microplastics with a density above that of water in the grit chamber. However, it is estimated that up to 80 % of microplastics are already separated in these two stages. Floating or very fine microplastics, on the other hand, are mainly deposited in sewage sludge. However, the grit is often washed for recycling. The separated substances are added to the sewage sludge.

In relation to the wastewater treatment plant outlet, wastewater treatment plants achieve a removal efficiency of 98 to 99.99 % for microplastics. Further removal efficiencies could be achieved by sand filters, micro screens, cloth filters or membrane plants. In view of the fact that large parts of microplastics do not enter the marine environment via the clear effluent of the wastewater treatment plant, the microplastic problem at least suggests other priorities in the wastewater system (use of sewage ludge in agriculture, treatment of precipitation water).

## 3.5 Interim summary

During the second workshop, a large number of sources were described and, at the same time, options for solutions were identified. Nevertheless, the above presentation cannot claim to be exhaustive. For example, off-shore industries or geotextiles in coastal protection were not considered. Fragmentation of littered plastics was also not addressed, as this is already the subject of various MSFD measures elsewhere. Building on the presentations and discussions, workshop participants were asked to make specific suggestions for measures. These were brought together, structured and prioritised in the third workshop and are summarised in the following chapter.

# 4 Fields of action and proposed measures

Based on the challenges and solution options identified in the first two workshops, the members of the RTM's sub-working group "Microplastics" discussed sensible proposed measures in a third workshop without the involvement of external experts. The aim of this workshop was to characterise and prioritise the proposed solution options with regard to their relevance for marine protection, the type of measure and the time frame for implementation (immediately, 5 years or later). The elaborated catalogue of measures ultimately serves to update and operationalise the national environmental objectives UZ5-03 "Avoiding the use of primary microplastic particles” and UZ5-09 “Reducing emissions and inputs of microplastic particles”, which are part of the revision of the MSFD. It provides the institutions responsible for the implementation of the Directive in Germany with the necessary basis for the further implementation of the solution options identified by the experts in practice. In addition, the catalogue is intended to make a significant contribution to the corresponding work at European and regional level.

All proposed measures are additionally summarized in tabular form in Appendix 1.

## 4.1 Cosmetics, washing and cleaning agents

### 4.1.1 Labelling of products containing plastics

Consumers can avoid the use of products containing plastics by observing the labelling. A common definition or understanding of what is meant by plastics in this sense (intended microplastics, dissolved, gel-like polymers or even microplastics through abrasion and weathering) would be an important prerequisite for this. There are various options for labelling: a) declaration of all ingredients on the packaging, both for cosmetics and for washing and cleaning agents, b) information apps (Beat the Microbead, Codecheck, Tox-Fox, etc.), c) “microplastic-free” manufacturer labels, d) recommendations for use by manufacturers.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, political, regulatory, behavioural, educational |
| Feasibility | immediately, in 5 years |

### 4.1.2 Voluntary renunciation of the use of plastic-containing products by manufacturers

Manufacturers assume environmental responsibility for their products and voluntarily dispense with products containing plastics. The basis is a common definition (see ECHA, DIN).

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, political, regulatory, |
| Feasibility | immediately, in 5 years |

### 4.1.3 Regulation of intentionally added microplastics

The ECHA proposal for the far-reaching restriction (up to a ban for specific applications) of intentionally added microplastics in products (substances and mixtures) envisages enshrining marine degradability a) as a requirement for substances in REACH or chemicals legislation and b) for all substances of washing, cleaning and sanitising agents.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | political, regulatory |
| Feasibility | in 5 years |

## 4.2 Pellet Loss

### 4.2.1 Equipping the existing OCS concept with externally validated certification

Equipping the existing concept of the European Operation Clean Sweep (OCS) with an externally validated certification for pellets of plastic materials from industrial applications, i.e. granulates, flakes, grit or powder.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | technical, political, regulatory |
| Feasibility | immediately, in 5 years |

## 4.3 Tire wear

### 4.3.1 Optimization of road cleaning facilities

- Wet road sweepings: Preventing tyre wear from entering the water cycle and thus reducing the potential risk of entry into water bodies. Examine legal requirements concerning the introduction of road sweepings into the wastewater treatment

plant, e.g. introduction of filters. Examination of technical solutions and adaptation of the legal framework
- Logistics in the street cleaning process must be optimised (timing, type of cleaning)
- Equipping street runoff with filter inserts to retain tyre wear material, e.g. at hotspots or at locations where direct discharge without subsequent treatment is potentially possible.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, political, regulatory |
| Feasibility | in 5 years |

### 4.3.2 Adaptation of traffic concepts

Adaptation of traffic concepts (traffic flow, speed limits, green wave, road surface).

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | political, regulatory |
| Feasibility | in 5 years |

### 4.3.3 Raising awareness of the impact of the choice of tyre quality and driving behaviour

Raising awareness of tyre quality and driving behaviour.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | behavioral, educational |
| Feasibility | Immediately |

### 4.3.4 Feeding into combined sewer system (no separating system)

No separate sewerage system, but expansion of combined sewerage system with the aim of minimising direct discharge. Subsequently determine treatment in the wastewater treatment plant.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, political, regulatory, |
| Feasibility | immediately, in 5 years |

### 4.3.5 Reduction of wear due to new tyre materials

Further development of new tyre materials with less wear, use of new materials (promotion of research, establishment of a wear test, definition of specifications regarding tyre wear).

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | technical, political, regulatory |
| Feasibility | later |

## 4.4 Playing fields and sports facilities, artificial turf, etc.

### 4.4.1 Restraint measures, better management for existing places

Development and implementation of retention measures/management for existing sites (installation of barriers, filters, brushes; optimization of maintenance measures; user training; replacement of infill with plastic-free alternatives).

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, behavioural, educational |
| Feasibility | in 5 years |

### 4.4.2 Microplastic free infill

Further development, evaluation and use of alternative microplastic-free infill (e.g. from cork, sand, coconut fibres, olive kernel meal or granulates from (native) woods).

| Criterion | Characteristics |
|---|---|

| | |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical |
| Feasibility | in 5 years |

### 4.4.3 Technical containment measures and material alternatives

Determination of all sources of microplastic release in the area of environmentally open sports and play facilities (riding and golf courses, tartan tracks, playgrounds, etc.); determination of transfer rates to water bodies/oceans; further development, evaluation, recommendation and regulation of technical containment measures and material alternatives.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, political, regulatory, behavioural, educational |
| Feasibility | immediately, in 5 years |

## 4.5 Textile fibres

### 4.5.1 Development of new manufacturing technologies and materials

Development of lower-emission textiles and better processing technologies.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | technical |
| Feasibility | in 5 years |

### 4.5.2 Prewashing of the textiles

Prior to shipping to retail, an initial wash and dry cycle is performed to reduce free textile fibres (via EPR in the supply chain; taking care of what happens to the suds).

If applicable, criterion under the Green Button (BMZ initiative).

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | political, regulatory |
| Feasibility | in 5 years |

### 4.5.3 Washing machine filter

Drain of the washing machine is equipped with a filter / strainer.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical |
| Feasibility | in 5 years |

## 4.6 Building materials and coatings

### 4.6.1 Reduce polystyrene foams

A bundle of measures is proposed for the reduction of inputs:

- Zero pellet loss initiatives in the construction industry
- Requirements for material and waste safety on construction sites
- Temporary precipitation filters around construction sites
- Developments and specifications for low-emission processing techniques
- Extension/application of the Construction Products Regulation
- Development, testing and evaluation of alternative insulation and aggregate materials

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | technical, political, regulatory, behavioural, educational |
| Feasibility | in 5 years, later |

### 4.6.2 Reduce the use of plastics in environmentally friendly applications

Reduce the open use of plastics in the marine/coastal environment, e.g. geotextiles, corrosion protection, elastomers in revetments.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | technical, political, regulatory |
| Feasibility | Immediately, in 5 years |

### 4.6.3 Reduce input of microplastics from paints in environmental applications

- Determination of release and transfer rates to the environment
- Material development
- Testing and evaluation to reduce abrasion rates and increase degradability
- Minimum standards for shelf life, use

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | Medium |
| Type of measure | technical, political, regulatory |
| Feasibility | in 5 years, later |

## 4.7 Ship coatings

### 4.7.1 Handling of ship coatings in shipyards

- Legal regulation to ensure that wastewater from shipyards (e.g. leakage water/process water/cleaning water from halls) does not exceed microplastic limits yet to be defined.
- Mandatory containment of releases when dry blasting is used (e.g. by containment tent)
- Legal regulation to avoid paint drift when applying paint with spraying methods, e.g. by electrostatically charged spraying methods (reduced by 40 % politically), politically, only within the dock edge, etc.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, political, regulatory |
| Feasibility | in 5 years, later |

### 4.7.2 Reduction/avoidance of polymer inputs from coatings (insoluble polymer particles) of ships and boats

Installation of fenders permanently installed on the hull (cruise ships) or perimeter guard rails.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | political, regulatory, behavioural, educational |
| Feasibility | Sync and corrections by n17t01 |

### 4.7.3 Avoidance of polymer inputs from antifouling coatings (soluble polymer compounds) in commercial shipping

Avoiding the use of antifouling coatings, such as*:*

- Foul release coatings
- Hard coatings with cleaning
- Foil systems
- Fibre coating
- Early and demand-oriented cleaning instead of coating
- Carrying out studies on the hydrolysis of polymer compounds from paint coatings from sea-based uses as a basis for risk assessments

Biocide-free solutions should be preferred when weighing up the choice of an anti-fouling system.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | political, regulatory, behavioural, educational |
| Feasibility | Immediately |

### 4.7.4 Avoidance of polymer inputs from antifouling coatings (soluble polymer compounds) of recreational boats

Raising awareness among recreational boat owners about existing environmentally friendly alternatives for coatings (see leaflet Pestizid Aktionsnetzwerk e. V. Germany “Alternativen zu Biozid-Antifoulings”[14])

[14] Engl.: Alternatives to biocide based antifoulings

with the aim of avoiding the use of antifouling coatings in recreational boating and instead using alternatives such as abrasion-resistant, biocide-free hard coatings.

Measures to reduce fouling of hulls without antifouling, e.g. by the use of lifts at the berth for smaller boats, barriers at the berth such as foils or mats or regular mechanical or manual cleaning; for this purpose, installation of appropriate washing stations, e.g. in the marinas in Sweden (there are already washing stations for boats without antifouling coatings).

Sport boats are equipped with efficient collection and filtration of the wash water.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, political, regulatory, behavioural, educational |
| Feasibility | Immediately, in 5 years |

## 4.8 Biodegradable plastics

### 4.8.1 Development of standards/norms to derive specifications

Development and implementation of standards/ norms to determine (bio)degradability under diverse marine conditions.

If applicable, establish critical residence time in marine environmental compartments <- budget approach.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | technical, political, regulatory |
| Feasibility | in 5 years, later |

## 4.9 Water Management

### 4.9.1 Equipment with post filtration

Equipping the wastewater treatment plants with an additional filtration stage (sand filter, micro screen, cloth filter, membrane filter).

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | technical, political, regulatory |
| Feasibility | in 5 years, later |

### 4.9.2 Combined Sewer Treatment

All sewer water is treated through the wastewater treatment plant or sedimentation tank /soil filters.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | technical, political, regulatory |
| Feasibility | in 5 years, later |

### 4.9.3 Rainwater treatment

Before discharge into watercourses via filters/ decentralised soil filters.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | high |
| Type of measure | technical, political, regulatory |
| Feasibility | in 5 years, later |

### 4.9.4 Sewage sludge treatment

Ban on the spreading of sewage sludge in agriculture (only incineration and phosphorus recovery).

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |

| | |
|---|---|
| Type of measure | political, regulatory |
| Feasibility | Immediately, in 5 years |

## 4.10 Compost, fermentation residues

### 4.10.1 Reduction of the proportion of plastics in biowaste

Legal regulations must be reviewed and adapted in order to prevent the input of plastics via biowaste into agriculture (fermentation residues, composts, etc.), by reducing the limit values in the relevant ordinances.

| Criterion | Characteristics |
|---|---|
| Relevance for marine protection | medium |
| Type of measure | political, regulatory |
| Feasibility | in 5 years |

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# Attachments

## Annex 1: Table of measures

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| 1 | Cosmetic, washing and cleaning agents | medium | 1.1 | Labelling of products containing plastics | Consumers can avoid products containing plastics through labelling. The basis is a common definition (see ECHA, DIN). There are various possibilities for this: a) Declaration of all substances on the packaging of cosmetics as well as washing and cleaning agents, b) Apps providing information (Beat the Microbead, Codecheck, Tox-Fox, etc.), c) "Microplastic-free" manufacturer labels, d) Recommendations for use by the manufacturers. | x | x | x | x | x | |
| | Cosmetic, washing and cleaning agents | medium | 1.2 | Voluntary renunciation of the use of plastic-containing products by manufacturers | Manufacturers take environmental responsibility for their products and voluntarily dispense with products containing plastics. Basis is a common definition (see ECHA, DIN). | x | x | | x | x | |
| | Cosmetic, washing and cleaning agents | high | 1.3 | Legal restriction of intentionally added particulate microplastics | ECHA proposal to restrict (here in particular ban) intentionally added particulate microplastics: enshrine marine degradability a) as a requirement for substances in REACH or chemicals legislation, b) for all substances of washing, cleaning and sanitising agents. | | x | | | x | |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| 2 | Tire wear | medium | 2.1 | Optimization of street cleaning possibilities | a) Wet road sweepings: Preventing tyre wear from entering the water cycle and thus reducing the potential risk of discharge into water bodies. Examine legal requirements concerning the introduction of road sweepings into the wastewater treatment plant, e.g. introduction of filters. Examination of technical solutions and adaptation of the legal framework<br>b) Logistics in the street cleaning process must be optimised (timing, type of cleaning)<br>c) Equipping street runoff with filter inserts to retain tyre wear material, e.g. at hotspots or at locations where direct discharge without subsequent treatment is potentially possible. | x | x | | | X | |
| | Tire wear | high | 2.2 | Adaptation of traffic concepts | Adaptation of traffic concepts (traffic flow, speed limits, green wave, road surface) | | x | | | x | |

| Sources | | | Possible solution | | | | | | | | |
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| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| | Tire wear | medium | 2.3 | Raising awareness of the impact of the choice of tyre quality and driving behaviour | Raising awareness of tyre quality and driving behaviour | | | x | x | | |
| | Tire wear | medium | 2.4 | Drainage into combined sewer system (no separating system) | No separate sewerage system, but expansion of combined sewerage system with the aim of minimising direct discharge. Subsequently determine treatment in the wastewater treatment plant. | x | x | | | | x |
| | Tire wear | high | 2.5 | Reduction of wear due to new tyre materials | Further development of new tyre materials with less wear, use of new materials (promotion of research, establishment of an wear test, definition of specifications regarding tyre wear) | x | x | | | | x |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| 3 | Playing and sports facilities: Artificial turf | medium | 3.1 | Retention measures, better management for existing pitches | Development and implementation of retention measures/management for existing pitches (installation of barriers, filters, brushes; optimisation of maintenance measures; user training; replacement of infill with plastic-free alternatives). | x | | x | | x | |
| | Playing and sports facilities: Artificial turf | medium | 3.2 | Microplastic-free infills | Further development, evaluation and use of alternative microplastic-free infills (e.g. from cork, sand, coconut fibres, olive kernel meal or granulates from (native) woods) | x | | | | x | |
| | Playing and sports facilities: general | medium | 3.3 | Technical containment measures and material alternatives | Determination of all sources of microplastic release in the area of environmentally open sports and play facilities (riding arenas and golf courses, tartan tracks, playgrounds, etc.); determination of transfer rates to water bodies/oceans; further development, evaluation, recommendation and regulation of technical containment measures and alternatives to materials. | x | x | x | x | x | |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| 4 | Biodegradable plastics | high | 4.1 | Development of standards/norms to derive specifications | Development and implementation of standards/norms for the determination of (bio)degradability under diverse marine conditions<br><br>If necessary, definition of critical residence time in marine environmental compartments <- Budget approach | x | x | | | x | x |
| 5 | Textile fibres | high | 5.1 | Development of new manufacturing technologies and materials | Development of lower-emission textiles and better processing technologies | x | | | | x | |
| | Textile fibres | high | 5.2 | Prewashing of the textiles | Before shipping to retail, an initial wash and dry cycle is performed to reduce free textile fibres (via EPR in the supply chain; taking care of what happens to suds)<br><br>If applicable, criterion under the Green Button (BMZ initiative) | | x | | | x | |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| | Textile fibres | medium | 5.3 | Washing machine filter | Washing machine drain is equipped with a filter/strainer | x | | | | x | |
| 6 | Pellet Loss | high | 6.1 | Equipping the existing OCS concept with externally validated certification | Equipping the existing concept of the European Operation Clean Sweep (OCS) with an externally validated certification for pellets of plastic materials from industrial applications, i.e. granules, flakes, grit or powder. | x | x | | x | x | |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| 7 | Building materials and coatings: polymeric insulating materials and lightweight aggregates in the construction industry | high | 7.1 | Reduce polystyrene foams | A bundle of measures is proposed for the reduction of inputs:<br>○ Zero Pellet Loss Initiatives of the Construction Industry<br>○ Requirements for material and waste safety on construction sites<br>○ temporary precipitation filters around construction sites<br>○ Developments and specifications for low-emission processing techniques<br>○ Extension/application of the Construction Products Regulation<br>○ Development, testing and evaluation of alternative insulation and aggregate materials | x | x | x | | x | x |
| | Building materials and coatings: Plastics in environmental applications | high | 7.2 | Reduce the use of plastics in environmentally friendly applications | Reduction of open use of plastics in the marine/coastal environment e.g. geotextiles, corrosion protection, elastomers in revetments | x | x | | x | x | |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| | Building materials and coatings: Paints and varnishes | medium | 7.3 | Reduce input of microplastics from paints in environmental applications | ○ Determination of release and transfer rates to the environment<br>○ Material development<br>○ Testing and evaluation to reduce abrasion rates and increase degradability<br>○ Minimum standards for shelf life, use | x | x | | | x | x |
| | Coatings in shipyards | medium | 7.4 | Optimisation of the handling of ship coatings in shipyards | ○ Legislation to ensure that wastewater from shipyards (e.g. leakage water/process water/ hall cleaning water) does not exceed microplastic limits yet to be defined.<br>○ Compulsory individual testing for dry blasting applications<br>○ Legal regulation to avoid paint drift when applying paint with spraying methods, e.g. electrostatically charged spraying methods (overspray reduced by 40 %), containment tent, only within the dock edge, etc. | x | x | | | x | x |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| | Coatings in the shipping industry | medium | 7.5 | Reduction/avoidance of polymer inputs from coatings (insoluble polymer particles) of ships and boats | Installation of fenders permanently installed on the hull (cruise ships) or circumferential protective strips | | x | x | x | | |
| | Coatings in commercial shipping | medium | | Avoidance of polymer inputs from antifouling coatings (soluble polymer compounds) in commercial shipping | The consideration for selecting an anti-fouling system should give priority to biocide-free solutions, such as:<br>○ Foul release coatings<br>○ Hard coatings with cleaning<br>○ Foil systems,<br>○ Fibre coating<br>○ early and demand-oriented cleaning instead of coating<br>○ Carrying out studies on the hydrolysis of polymer compounds from paint coatings from sea-based uses as a basis for risk assessments | | x | x | x | | |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | Relevance for marine protection | No | Title | Brief description | Measure type | | | Feasibility | | |
| | | | | | | technical | political, regulatory | behavioural, educational, | immediately | in 5 years | later |
| | Coatings in recreational boating | medium | | Avoidance of polymer inputs from antifouling coatings (soluble polymer compounds) of recreational boats | Raising awareness among recreational boat owners about existing environmentally friendly alternatives for coatings (see leaflet Pestizid Aktionsnetzwerk e. V. Germany “Alternativen zu Biozid-Antifoulings”) with the aim of avoiding the use of antifouling coatings in recreational boating and instead using alternatives such as abrasion-resistant, biocide-free hard coatings.<br><br>Measures to reduce fouling of hulls without antifouling, e.g. by the use of lifts at the berth for smaller boats, barriers at the berth such as foils or mats or regular mechanical or manual cleaning. Installation of appropriate washing stations, e.g. in the marinas in Sweden (there are already washing stations for boats without antifouling coatings).<br><br>Sport boats are equipped with efficient collection and filtration of the wash water | x | x | x | x | x | |
| 8 | Water management:<br><br>Wastewater Technology | medium | | Equipment with post filtration | Equipping the wastewater treatment plants with an additional filtration stage (sand filter, micro screen, cloth filter, membrane filter) | x | x | | | x | x |

| Sources | | | Possible solution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| | Water management:<br><br>Wastewater Technology | high | | Mixed sewerage treatment | All sewerage water is treated via the sewage treatment plant or sedimentation basin/soil filter | | x | | | x | x |
| | Water management:<br><br>Wastewater Technology | high | | Rainwater treatment | Before discharge into watercourses via filters/ decentralised soil filters | x | x | | | x | x |
| | Water management:<br><br>Wastewater Technology | medium | | Sewage sludge treatment | Ban on spreading sewage sludge in agriculture (only incineration and phosphorus recovery) | | x | | x | x | |
| | Water management:<br><br>Compost, fermentation residues | medium | | Reduction of the proportion of plastics in biowaste | Legal regulations must be reviewed and adapted in order to prevent the introduction of plastics via biowaste into agriculture (fermentation residues, composts, etc.); by reducing the limit values in the relevant ordinances. | | x | | | x | |