National Institute for Public Health
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Ministry of Health, Welfare and Sport

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Abrasive cleaning agents, paints and tyre wear

RIVM Report 2016-0026

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Synopsis

Tyres, paints and abrasive cleaning agents can release microplastic particles, which are distributed in soil, water and air. Tyre wear is the largest of these three sources, with a total emission in the Netherlands of 17,300 tons per year, followed by paint particles at approximately 690 tons per year. The abrasive cleaning agents are a much smaller source, at approximately 3 tons per year.

This follows from an investigation conducted by RIVM. For each source, the destination of the particles in the environment is quantified. The emissions into water are, respectively, 1,800 (tyre wear), 330 (paint particles) and 1 (microplastics of abrasive cleaning agents) ton per year.

The Dutch government formulated an ambition to use resources efficiently. The disappearance of the above-mentioned materials in the environment is incompatible with that ambition. Furthermore, the exposure of organisms to these anthropogenic sources should be prevented.

The investigation comprises an inventory of potential measures to reduce the release of microplastics. For each source, it is essential to create awareness amongst consumers and professionals in order to induce a change in behaviour. In addition to this, the release of microplastics can be reduced through innovation. Another option is to take measures that prevent the distribution of wear particles to the environment.

These measures can be stimulated by legal implementation, by voluntary agreements with professional associations, by financial stimuli such as subsidies, and awareness-raising campaigns to induce behavioural changes.

Keywords: microplastics, tyre wear, paint, abrasive cleaning agents, emissions, distribution, measures.

Publiekssamenvatting

Uit banden, verf en schurende reinigingsmiddelen kunnen plastic deeltjes vrijkomen die zich in bodem, water en lucht verspreiden. Bandenslijtsel is de grootste van deze drie bronnen, met een totale uitstoot naar het milieu in Nederland van ongeveer 17.300 ton microdeeltjes per jaar. Daarna volgen verfdeeltjes met ongeveer 690 ton per jaar. De schurende reinigingsmiddelen zijn een veel kleinere bron, ongeveer 3 ton per jaar.

Dit blijkt uit onderzoek van het RIVM. Per bron is aangegeven in welk deel van het milieu de deeltjes terechtkomen. Zo is de emissie naar water respectievelijk 1.800 (bandenslijtsel), 330 (verfdeeltjes) en 1 (microplastics uit schurende reinigingsmiddelen) ton per jaar.

De Nederlandse overheid heeft de ambitie om efficiënt om te gaan met grondstoffen. Daarin past het niet om deze materiaalstromen in het milieu te laten ‘verdwijnen’. Bovendien moet zo veel mogelijk worden voorkomen dat organismen aan deze milieuvreemde stoffen worden blootgesteld.

Het onderzoek bevat daarom ook een eerste inventarisatie van maatregelen om de uitstoot van microplastics te verminderen. Voor alle bronnen is het belangrijk om bij consumenten en bedrijven begrip te creëren voor maatregelen en het gedrag hierop aan te passen. Daarnaast kunnen innovaties eraan bijdragen dat banden en verf minder snel slijten. Een andere optie is om maatregelen te nemen die voorkomen dat slijtagestof zich in het milieu verspreidt.

De maatregelen kunnen worden gestimuleerd door ze wettelijk vast te leggen, branches vrijwillig overeenkomsten te laten opstellen, financiële prikkels zoals subsidies aan te reiken, en voorlichtingscampagnes te ontwikkelen om gedragsverandering te stimuleren.

Kernwoorden: microplastic, banden slijtage, verf, schurende reinigingsmiddelen, emissies, verspreiding, maatregelen.

Contents

Summary

According to the Marine Strategy Framework Directive 2008/56/EC (MSFD), research must be conducted on the amount, occurrence and the sources of microplastics, and on measures that can reduce the emissions of microplastics.
To support the development of effective and efficient action plans by the Dutch government, RIVM published in 2014 an inventory and prioritization of land-based sources of microplastics [1]. The prioritization of land-based sources was scored based on a first qualitative evaluation of three criteria: 1) volume of the emission, 2) feasibility of measures and 3) action perspectives for consumers. The current report is a follow-up study to three prioritized land-based sources: 1) abrasive cleaning agents, 2) paints and lacquers and 3) rubber tyres. The aim was to quantify emissions of microplastics from these sources in the Netherlands and to propose potential measures for reduction of microplastics. The study was announced by the Dutch government in the MSFD Programme of measures.

Definition
Microplastics are solid, synthetic polymer particles with a size smaller than 5 mm, with a low solubility in water and a low degradation rate. Microplastics may contain non-polymeric additives, oils, fillers or other product aids. The mass of these inherent ingredients is included in the emission calculations. However, external substances or materials attached to microplastics during or after their use phase, such as road dirt to tyre wear particles, are not included in the emission calculations.

Detergents
We screened >400 (abrasive) cleaning agents of six market-leading companies and found that ten products were suspected of containing microplastics. These microplastics serve as abrasive agents. It all concerned products used to clean floors. Based on market data, it was estimated that the total emission of microplastics from abrasive cleaning agents is 2.6 tons/year, which is almost completely discharged into the sewer. Emissions to surface water are estimated to be 1.2 tons/year. The most likely measures to reduce emissions into surface water are a legal ban or the gradual, voluntary phase-out of microplastics in detergents. These are measures that need to be taken by the responsible producers.

Paints
Paint particles are considered as microplastics because they have a backbone of polymers. For the building sector, a total emission of 490 tons was estimated. In respect of paints, applications in the building and shipping sector were determined to be responsible for the largest part of paint use. In the building sector, a distinction is made between professionals and do-it-yourself (DIY) consumers. The amount of plastics that are released by removal of old paint layers, by the tear and wear of paint and by the rinsing of rollers and brushes coated with water-soluble wall paints is taken in to account. Emissions to surface water are estimated to be 130 tons per year. For shipping, the removal of paint at shipyards and marinas, as well as the wear and tear during shipping are quantified. In the shipping sector, it is estimated that 200 tons of microplastics per year are released to surface water.

A variety of measures could be considered to reduce the volume of paint particles. The most feasible seem to be measures that aim to reduce the wear of paints (paint innovation, way of application, maintenance), to prevent the spreading of dust and to create awareness with respect to rinsing brushes and rollers.

Rubber tyres
Road transport vehicle tyres were estimated to contribute 1,800 tons of particles from tyre tread wear per year into surface water through run-off from pavements, effluents and overflows of the sewage system, and 6,200 tons per year into soil. Additionally, another 900 tons per year of fine particulate matter from tyres are released to the air, and 7,400 tons per year are captured in open asphalt concrete roads. This pertains to the wear of tyres on nine different vehicle types: such as several types of trucks, passenger cars, buses and motorcycles. Potential measures comprise innovations made to tyres and road surfaces and the collection of run-off water, consumer awareness with respect to driving behaviour, tyre pressure and wheel alignment, the proper use of summer and winter tyres, and ways to reduce vehicle kilometres.

Uncertainties
The emission estimates in this report are often based on limited information and rely partly on expert judgement. For this reason, ranges of emissions to surface water are reported. It is recommended that research be conducted in order to fill some significant knowledge gaps. Towards the end, suggestions are given in this report.

Measures
Legal, economic, voluntary and persuasive instruments for a policy to reduce microplastics were discussed and supplemented with a list of potentially product-specific viable options. The measures proposed in this study should be subjected to further socio-economic analysis to determine the effectiveness, viability and the costs and benefits of the measures.
A generic measure could be the improvement of sewage treatment plants. In general, this end-of-pipe measure is less favourable than preventive source measures and measures that address the producer's responsibility. Furthermore, the current distribution of microplastics towards sewage treatment plants and removal efficiency of these plants are highly uncertain. These uncertainties must be reduced by specific research before end-of-pipe measures are introduced.

1 Introduction

Tasks from the Marine Strategy Framework Directive
This report presents facts and figures for three sources of microplastics — 1) abrasive cleaning agents, 2) paints and lacquers and 3) car tyre wear — and suggests potential measures to reduce the emission of microplastics from these sources. This task follows from the Marine Strategy Framework Directive 2008/56/EC (MSFD) and the related Commission decision 2010/447/ on criteria and methodological standards on the good environmental status of marine waters [2]. The latter document mentions microparticles and, in particular, microplastics as one of the indicators of a good ecological status of the marine environment. According to the MSFD, member states must develop monitoring methods in order to follow trends in the amounts and the occurrence of microplastics. Furthermore, research must be conducted into the sources of microplastics and into potential measures that can reduce the quantity of microplastics [3].

Origin of microplastics
Nowadays, plastic has penetrated virtually every single aspect of everyday life: from clothing to electronics and from building materials to cleaning products. Due to littering, wear, imperfect waste management systems, sewage and industrial sources, plastic enters the environment. Some plastics consist of very tiny particles, known as microplastics: generally defined as solid polymer-based materials with a size of <5 mm. Yet larger plastic items also contribute to the microplastic load. Through mechanical wear and oxidation, plastic disintegrates and falls apart into smaller pieces and microplastics. Concerns have been raised because microplastics are found in both the marine and freshwater aquatic environments: in water, in sediments and in biota, such as fish, mussels and crustaceans [4, 5]. Apart from the protection of aquatic ecosystems, food safety is also an issue that is raised in relation to microplastics.

Previous work
To support the development of effective and efficient action plans by the government, RIVM published an inventory and prioritization of land-based sources of microplastics [1]. The reduction of land-based sources is relevant because it is estimated that a significant part of the plastic found in the marine environment originates from such land-based sources [6]. The prioritization of land-based sources was scored based on a first qualitative evaluation of three criteria: 1) volume of the emission, 2) feasibility of measures and 3) action perspectives for consumers. It was recommended that follow-up studies be launched in order to include more process-specific or industry-specific information and monitoring data as microplastic sources with the highest priority scores. The priority list is shown in Table 1.

Follow-up
A follow-up study on three product groups was demanded by the Ministry of Infrastructure and the Environment of the Netherlands and subsequently announced by the Dutch government in the MSFD Programme of measures: 1) abrasive cleaning agents, 2) paints and lacquers and 3) rubber tyres [1]. The latter group includes the tyres of

nine different vehicle types: such as several types of trucks, passenger cars, buses and motorcycles. Several other high priority sources were not selected for the follow-up for practical and financial reasons. It was acknowledged that packaging/litter/waste collection is a significant source of microplastics, but this source has already been subjected to measures, regulations and green deals. Cosmetics also received a high priority, but this source has already been subjected to voluntary measures by the association of manufacturers and importers of cosmetics and products for personal care in the Netherlands. The Plastic Soup Foundation watched for the effectiveness of these voluntary measures as part of their "Bead the microbead" campaign (http://beatthemicrobead.org/en/product-lists). The issue of fibres and clothing was temporarily parked, awaiting the results of a Dutch exploratory study by Milieu Centraal and the results of a EU-financed Life+ research project called “Mermaids” (http://life-mermaids.eu). Loading, unloading and the transfer of plastic pellets was not further explored for now because industries initiated a voluntary Zero Pellet Loss programme, also referred to as Operation Ocean Clean Sweep.

Table 1 Land-sources of microplastics and their priority adapted from RIVM Quick scan study [1].

Priority score	Activity/product
9	Packaging material
8	Litter (general)
7	Waste collection
	Cosmetics
	Paint, lacquer, dyes
	Fibres and clothing
	Loading, unloading, transfer
	Runoff from paved surfaces
6	**Tyre wear**
	Abrasive cleaning agents
	Dust from construction sites
	Inflow from abroad
	Agricultural plastics
	Compost, sewage sludge
	Treated water
	Overflow and untreated water
5	Composting installations
	Glues, adhesives
	Insulation, construction materials
	Cast floors, carpeting
	Household items
	Automotive businesses
	Dry cleaners
	Cleaning of tankers
	Sports fields
4	Foodstuffs and snacks
	Landfill sites
	Fibres
	Packaging
	Granular material (DIY)
	Medical resources
	Toys and party items
3	Combustion
	Sandblasting
	Granular material
	Foodstuffs and snacks
	Glues and adhesives
	Shipyards
	Rotary milling
	Atmospheric deposition
2	Preparation of recycling
	Production of base chemicals
	Medical resources
	Electronics devices
	Dental surgeries
	Corrosion of water mains
	Extraction and distribution
	Cooling water
	Aviation
1	Pesticides/herbicides
	Printing firms

Aims
This research study aims to answer the following questions, for abrasive cleaning agents, paints and tyres:

- Which components or ingredients of the three products mentioned above are considered to be microplastics?
- What is the release pathway and what are the amounts of microplastics released during the use or application of these products in the Netherlands?
- Which potential measures can be taken to reduce these emissions and how sustainable are these measures?
- What kind of generic measures can be taken to reduce microplastic emissions regardless of their source?

These questions are answered based on literature and desktop research, experimental research and input from stakeholders. Additionally, more details are collected about the appearance of the microplastics, why they are used and how they are distributed in the environment.

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- Dutch Association of Paint and Ink Manufacturers, Martin Terpstra, www.vvvf.nl
- Dutch Polymer Institute, Monique Bruining, www.dpi.nl
- Plastics Europe NL, Theo Stijnen, www.plasticseurope.org
- Plastic Soup Foundation, Jeroen Dagevos, www.plasticsoupfoundation.org
- Lydia Harkink, Unie van Waterschappen, www.uvw.nl

This report does not necessarily represent the opinions of abovementioned organizations or representatives.

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2 Identification and distribution of microplastics

2.1 Definition of microplastic

A legally binding European definition of microplastics does not exist. Therefore, we use a description which was proposed by RIVM and submitted to the EPA-network for further discussion with other European Member States [7]. This working definition is shortly described below.

A review of existing proposals and working definitions indicates that there are five major elements that should be specified in order to determine whether a compound is a microplastic. These elements are: composition, physical state, solubility, degradability and size. Each element is further specified and the selected threshold values were adopted or derived from widely used and accepted legal frameworks. The following criteria, put forward in the same review, are used in this report.

Table 2 Elements of the microplastics definition in this study

Elements	**Provisional criteria**		**Adopted from:**
Composition	Synthetic polymer-based materials		ISO [8], REACH [9]
Physical state	A substance that is not a liquid or a gas.		UN-GHS [10]
Size	<5 mm		MSFD [11]
Solubility	< 1 mg/L		REACH [12]
Degradability	Compartment	Half-life	REACH [13]
	Marine water	< 60 days	
	Fresh or estuarine water	< 40 days	
	Marine sediment	<180 days	
	Fresh or estuarine sediment	<120 days	
	Soil	<120 days	

Microplastics may contain non-polymeric additives, oils, fillers or other product aids. The mass of these inherent ingredients is included in the emission calculations because they form an inevitable part of the microparticles. Moreover, the effect of microplastics is determined by the total volume, shape and reactivity of the microparticles and not by the polymer ingredients alone. However, external substances or materials attached to the outer surface of the microplastics during or after the use phase, such as road dirt to tyre wear particles, are not included in the emission calculations.

2.2 Distribution of microplastics

Microplastics can be released into the air, soil and surface water (directly or indirectly via a sewer). A general distribution scheme for the discharges into water was retrieved from the Dutch Pollutant Release and Transfer Register (www.prtr.nl), see Figure 1. A vital attenuator in the release pathways for a number of applications is the sewage treatment plant (STP). In the Netherlands almost all households (99.7%) are connected to a sewage system [14]. The removal efficiency depends on the type of sewerage system and the capacity and technical features of the STP. Reported removal efficiencies are very variable; removal percentages of 0-90% have been reported [15-17].

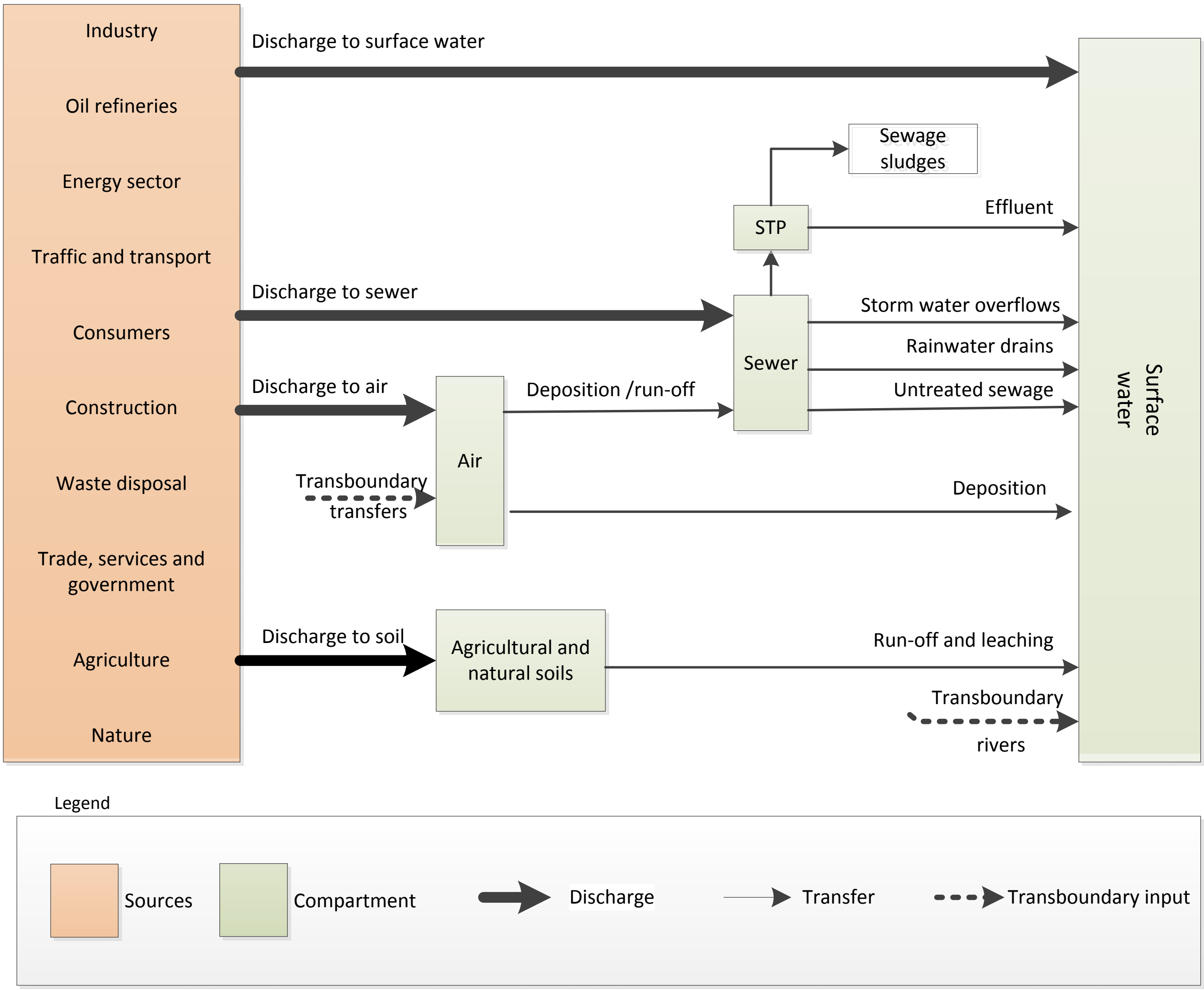

Figure 1 Sources and routes of plastics/microplastics to surface water (www.prtr.nl).

The residues of the STP, the sewage sludge, could be a source of microplastics too. In the Netherlands, the application of sewage sludge on agricultural land is prohibited [18], sewage sludge is generally incinerated; therefore there is no pathway from sewage sludge to the surface water. However, this may be a significant route in other countries.

This report aims to quantify the direct emission of microplastics from abrasive cleaning agents, paints and tyres to the four compartments shown in Figure 1 (the bold black arrows). Subsequent exchange and redistribution over the compartments long after the emission has taken place is not taken into account. Redistribution occurs, for example, through the deposition of dust particles into soil, through precipitation and the resuspension of particles in water and sediment, and through the flooding of rivers.

2.3 Sewerage systems in the Netherlands

Most of the present sewer systems (approximately 70%) in the Netherlands are combined systems with both storm water and waste water being treated in a communal waste water treatment plant [19]. A disadvantage of these systems is that at high rainfall, the capacity of these systems and the treatments plants is insufficient, resulting in an overflow of storm water and wastewater to the surface water. In separated sewerage systems, the wastewater from streets is discharged directly into the surface water without treatment. This concerns approximately 20% of the sewerage systems. The capacity of the sewage treatment plant can then be reduced and better tuned to the relatively constant amount of municipal wastewater. A disadvantage is the direct discharge of relatively contaminated run-off water from streets into the surface water without treatment. The newer, improved separated systems (10% of the systems in the Netherlands) will transfer the first part of the storm water (including street dirt) to the wastewater treatment plant, whereas the subsequent cleaner part is still discharged directly into the surface water.

In highly paved areas, microplastics are washed away with street dirt to the sewerage system. The distribution of emissions from paint to sewer, soil and surface water is not specifically described in the Dutch Pollutant Release and Transfer Register. Emissions from the abrasion of tyres within urban areas are allocated to sewer (60%) and soil (40%), while emissions from the abrasion of tyres outside urban areas are allocated to surface water (10%) and soil (90%) [20]. Emissions from several other emissions sources within urban areas are allocated similarly [21, 22].

Only limited data is available on the treatment efficiency of sewage treatment plants with regard to microplastics. In a study conducted by the Institute of Environmental Studies (IVM) at VU University Amsterdam, in collaboration with Deltares, Delft University of Technology and the Hollandse Delta Water Board, research was conducted into the presence of microplastics in various flows at the Heenvliet sewage treatment plant [15]. In this exploratory study, which only included a few samples, 90% of the microplastic particles were removed by the treatment process. The remaining 10% entered the surface water, from where it can reach the sea. In a follow-up study, the number of sewage treatment plants was increased to three and a larger number of samples were taken. The previous estimate for treatment efficiency (90%) was not confirmed by the follow-up study. Microplastics were detected in the effluent (on average 39-89 microplastic particles per litre). This confirms that microplastics are not entirely removed from water by sewage treatment plants [23]. It turned out that the concentration of microplastics varied with time, and that effluent concentrations were not always lower than influent concentrations. A recent study conducted by four Dutch sewage treatment plants shows average microplastic concentrations in effluent of between 48 and 55 particles per litre [16].

Part of the contamination in wastewater and storm water is removed prior to the STP by traps and sedimentation devices. This concerns approximately 8-9% of the contamination ending up in sludge. A preliminary removal rate in the STP of 50% is employed, but a range (10-90% removal) is reported as well. This means 50% of the microplastics in the treated wastewater will be transferred to the effluent and an equal part is transferred to sewage sludge. The amount in sludge consists of 2 streams: 1) amount of microplastics removed during the treatment and, 2) the amount captured in sedimentation devices prior to treatment. The latter amounts to 9% for wastewater and 8% for storm water.

Plastic particles removed during treatment in the STP end up in the sewage sludge. Also sludge from sedimentation devices in the sewerage system may contain microplastics. In some countries, the application of sewage sludge on agricultural land for soil improvement and fertilizer is still allowed. In this way, microplastics are reintroduced in the environment. In the Netherlands, this practice is not allowed and the communal sewage sludge is further processed and ultimately incinerated. Currently, several initiatives to reuse or recycle wastewater and sludge are being considered. Several resource recovery and sanitation technologies are still in an experimental stage. Once brought forward to the operational stage, these new technologies will influence, either positively or negatively, the environmental load of contaminants such as microplastics and other contaminants. The following technologies could be of concern because of either possible increases of microplastic emissions or unfavourable changes in their exposure routes: products recovered from the STP, digestion of sewage sludge, use of concentrates to replace chemical fertilizer, co-digestion or composting of manure [24].

Based on the factsheet of the Pollutants Release and Transfer Register on sewerage systems in the Netherlands [25], the approximate composition of the Dutch sewer system and emissions of municipal waste water and storm water to surface water is given in Table 3.

Table 3 Distribution of microplastics in the sewerage system of the Netherlands. Percentages are expressed as percentage of total emission of microplastics in wastewater or storm water that enters the sewerage system. Derived from [25].

Water stream	**Untreated[a]**	**Effluent[b]**	**Sludge[c]**	**Total**
Wastewater[a]	0.5%	45%	54%	100%
Range		9-82%	18-91%	
Storm water[b]	20	36%	44%	100%
Range		7-65%	16-74%	

[a] The fraction of wastewater that is treated is 90.8%. With a removal rate of 50% in the STP, approximately 45% ends up in effluent (90.8%x50%) and 45% ends up in sludge. The remaining part is either untreated (directly discharged to surface water 0.5%) or captured in sludge prior to treatment (9%). Total sludge is thus 45%+9% =54%.

[b] The fraction of storm water that is treated is 72%. With a removal rate of 50% in the STP, approximately 36% ends up in effluent (72%x50%) and 36% ends up in sludge. The remaining part is either untreated (directly discharged to surface water: 20%) or captured in sludge prior to treatment (8%). Total sludge is thus 36%+8% =44%.

In the Dutch Pollutants Release and Transfer Register (PRTR), advanced calculation methods are available for even eight different types of sewerage systems. PRTR data are linked to geographical locations, which enables regions with high exposure to be identified. In this report, a simplified approach was chosen, using average emission factors (see Table 3 and Table 4).

Considering the processes above, the emission of microplastics in wastewater (WW) to surface water (SW) can be computed as follows:

$$Emission_{WW \rightarrow SW} = Usage \times \{ F_{direct} + F_{untreated} + F_{effluent} \}$$

Table 4 Input parameters for the calculation of microplastic emissions from wastewater to surface water.

Parameter	Description	Value
F_{direct}	Fraction of wastewater directly discharged to surface water	0.003
$F_{untreated}$	Fraction of wastewater discharged to surface water by wastewater overflow	0.005
$F_{effluent}$	Fraction of microplastics present in effluent	0.45

The emission of microplastics in storm (rain) water (RW) via STP to surface water (SW) can be computed as follows:

$$Emission_{RW \rightarrow STP \rightarrow SW} = Usage \times \{ F_{direct,rural} + F_{STP,urban} \times (F_{untreated} + F_{effluent}) \}$$

Table 5 Input parameters for the calculation of microplastic emissions through storm water run-off to surface water.

Parameter	Description	Value
$F_{STP,urban}$	Fraction of urban storm water discharged to the STP	0.6
$F_{direct,rural}$	Fraction of rural storm water directly discharged to surface water	0.1
$F_{untreated}$	Fraction of wastewater discharged to surface water by storm water overflow	0.2
$F_{effluent}$	Fraction of microplastics present in effluent	0.36

3 Abrasive cleaning agents

3.1 Introduction

Cleaning is essential for hygienic or safety reasons. For instance, it reduces the risk of bacterial food contamination or it prevents surfaces from becoming slippery. Cleaning prolongs the service life of materials because dirt causes the deterioration of materials. Last but not least, cleaning enhances the aesthetic value (look and feel) of materials. Consumers demand detergents that are, in the first place, effective and that save time. In modern society, time-consuming cleaning activities are not appreciated. It seems that, for most consumers, environmental issues come in second or even third place (behind financial reasons) when choosing to purchase a cleaning product.

In 2014, Dutch consumers spent €122 per household (= €53 per capita) on detergents. Approximately 10% was spent on products for the maintenance of surfaces and 25% was spent on cleaning products. Around 65% was used for dishwashing and laundry detergents [26].

Detergents are used for cleaning because they facilitate or enhance the removal of dirt. Detergents fall under the jurisdiction of the Regulation (EC) No 648/2004 of the European Parliament and the Council of 31 March 2004 on Detergents. Detergents are defined in this regulation as:

"any substance or mixture containing soaps and/or other surfactants intended for washing and cleaning processes. Detergents may be in any form (liquid, powder, paste, bar, cake, moulded piece, shape, etc.) and are marketed for or used for household or institutional or industrial purposes."

Other products to be considered as detergents are:

- 'Auxiliary washing mixture ', intended for soaking (pre-washing), rinsing or bleaching clothes, household linen, etc.;
- 'Laundry fabric-softener', intended to modify the feel of fabrics in processes, which are meant to complement the washing of fabrics;
- 'Cleaning mixture', intended for domestic all-purpose cleaners and/or other cleaning of surfaces (for instance materials, products, machinery, mechanical appliances, means of transport and associated equipment, instruments, apparatus, etc.);
- 'Other cleaning and washing mixtures ', intended for any other washing and cleaning processes.

Polishing waxes (e.g. for furniture, floors and cars) are not covered by the Detergent Regulation, because they do not contain soap. These products are therefore not subject of our investigation.
Applications of microplastics in (industrial and consumer) hand soaps, facial scrubs, and bath and shower products are also outside the scope of this report because these products are not considered detergents, but rather personal care products, and these fall under the EU Cosmetics Directive 76/768/EEC and the EU Cosmetic Products Regulation (EC) No 1223/2009.

The Detergents Regulation states that all ingredients contained in detergents must be publicly available, although this information is not always easy to find. First of all, most consumers do not know which chemicals are considered to be microplastics. Microplastic ingredients are not explicitly indicated as such, yet they are described by their chemical name, such as polyethylene. Polyethylene, however, is not necessarily present in the form of a microplastic. Secondly, information on consumer products is often not present on the packaging, but is only available on the Internet. Detergents for the professional market are accompanied by a Safety Data Sheet containing information on ingredients and their hazards.

3.2 Why are microplastics used?

Four factors contribute to effective cleaning: mechanical force (motion), chemicals, duration and temperature. Together, they determine the cleaning result. Abrasives are added to some detergents to increase the motion and, as a result, less aggressive chemicals are necessary or less time is needed to obtain the same result.

Abrasive cleaners are used in households to clean floors, surfaces and equipment and work pieces, mainly in kitchens and bathrooms. The materials to be cleaned can be wood, metal, plastic, ceramic, composite or painted surfaces.

In order to exhibit an effective abrasive function, particles should have a size of between 50 and 1000 µm. Particles of this size are referred to as microbeads. Polymer ingredients which function as, for example, a stabilizer, viscosity controller, soil release and anti-static agents are generally much smaller than the microbeads, but can be regarded as microplastics too.

In the past, abrasives were made of natural mineral components, such as sand (silica) or clay. Nowadays, an artificial abrasive, such as calcite (calcium carbonate), is a common ingredient of cleaning agents. Calcite is a cheap and effective cleaning agent, but for some surfaces it is too hard and aggressive. For ceramic furnaces and stainless steel surfaces in the kitchen, special surface abrasives exist which have a cleaning and a mild polishing effect. They usually contain aluminium oxide or silicium oxide as abrasive ingredient, instead of calcite. In particular cases, microplastic particles are used as abrasives in abrasive cleaning agents because of their mild abrasive action.

An abrasive that is too hard or too coarse can remove too much material or leave undesired scratch marks. Excessive abrasion or the presence of scratches may:

- diminish or destroy usefulness (for instance scratching optical lenses and compact discs or dulling knives);
- trap dirt, water or other material;
- increase surface area, permitting greater chemical reactivity such as increased rusting
- erode or penetrate a coating (such as a paint);
- cause an object to wear away quickly (such as a blade or a gemstone);
- increase friction (as in jewelled bearings and pistons).

A finer or softer abrasive will tend to leave much finer scratch marks. The softer abrasive may, however, become less effective more quickly as the abrasive is itself abraded.

Plastic particles are generally softer than mineral particles, but they are more expensive. For this reason, they are used only in products that are specifically designed to clean delicate surfaces.

3.3 Which products contain microplastics?

Detergents are divided in five different groups: laundry detergents, dishwasher detergents, bathroom cleaners, bleaching cleaners and surface cleaners. Abrasives are mainly used to clean hard surfaces. Abrasives are covered by the term ‘microbeads’. This study focuses on abrasive cleaning agents, so only the microbeads are under investigation. The emission of microplastics from laundry detergents fall outside the scope of our study. There are, however, indications that persistent and non-soluble polymers are also being used in certain laundry detergents. For instance, polypropylene terephthalate was found as an ingredient in several laundry detergents on the Dutch market. A large European research project focused on laundry detergents is currently being conducted by Italian and Spanish scientists in the Mermaids project. Results are expected to be published in 2016. Depending on the outcome of the Mermaids project, follow-up steps can be triggered.

Many polymeric or other types of surfactants or product aids are being used in detergents. Examples are polycarboxylates, non-ionic surface active ingredients (alcoholethoxylates, alkyl polyglycosides), anionic surface active ingredients (linear alkyl benzenesulphonate, alkyl sulphate and alkyl ethersulphate), cationic surface active ingredients (quaternary ammonium salts) and amphoteric surface active ingredients (aminoalkyl amino acid, cocoamidopropyl betaine). Usually it concerns polymers with a high solubility and biodegradability. The surface active ingredients which are allowed on the European market are all considered safe and fulfil the criteria of the EC Regulation on Detergents (No 648/2004). This regulation states that all surfactants must be readily biodegradable.

Polymers in detergents with functions other than as a surfactant do not have to fulfil the readily biodegradability criterion. It is possible, therefore, that persistent polymer ingredients that function as, say, a stabilizer, viscosity controller, soil release and anti-static agents could still be allowed in detergents because their function is not defined as surfactant.

Many polymer ingredients and their functions are listed in the CosIng database (http://ec.europa.eu/growth/tools-databases/cosing/), which in essence is a database of substances used in personal care and cosmetic products, but it also contains ingredients of detergents. Another database is the Detergents Ingredients Database (DID-list), which contains the most common ingredients of detergents, their function and degradation potential and toxicity. The DID-list was set up as a source of information for assigning eco-labels to detergents. The rules for eco-labels have been laid down in EC Regulation 66/2010 (read more in Chapter 6.)

The composition of abrasive cleaning agents depends on the type of product. Common abrasive cleaners contain calcium carbonate. Polishing agents contain mainly aluminium oxide or silica (for fine abrasive function) or calcium carbonate (for more coarse grains). Agents for leather polishing and maintenance do not contain microplastics, but rather waxes.

We searched for product information on a variety of surface cleaners on the websites of six market-leading manufacturers on the Dutch market for cleaning products (Appendix 1).

Of the more than 400 products we screened, eight products for floor cleaning and two products for wood polishing contain ingredients that may be considered as microplastics. It is not clear whether all these ingredients are abrasive particles or that they have a different function, e.g. as synthetic waxes. Further verification by contacting the companies involved, eventually followed by chemical and microscopic analysis should confirm the precise nature and function of these ingredients. Products for cleaning glass ceramic plates and steel did not contain microplastics, but rather alumina, silica and/or quartz.

3.4 Estimated emissions

Emissions of microplastics into surface water are estimated from usage, market penetration and removal rates at sewage treatment plants.
The total emission of microplastics was estimated based on interviews conducted by the Dutch Association of Soap Manufacturers (NVZ) among their members. Members of NVZ cover 90-95% of the consumer market in the Netherlands, and approximately 66-85% of the professional market [26].

Table 6 Input parameters for the calculation of emissions to surface water.

Parameter	Households	Industry
Usage by NVZ members (ton/year)[1]	2[1]	0.25
market share	90-95%	66-85%

[1]The NVZ-estimate of 2 tons of microplastics per year for households seems plausible, considering the fact that most (abrasive) cleaning agents did not contain microplastics. In fact, it was quite hard to find cleaning agents that did contain microplastics.

To verify the plausibility of the emission data provided by NVZ (2000 kg of microplastics for households), we estimated the market penetration of abrasive cleaning agents that contain microplastics.

$$Market\ penetration = \frac{Emission/_{Market\ Share}}{F_{microplastic} \times PopDens \times Usage}$$

In order to do so, it was assumed that:

1. a person buys and uses 500 g of abrasive cleaning agent per year;
2. microbead content in abrasive cleaning agents (when present) $F_{microplastic}$ is 6%;
3. population density in the Netherlands is 16.9 million.

Using these inputs, a market penetration of 0.5% was calculated for abrasive products that contain microplastics. Given the uncertainties in the calculation, amounts of 2.6 tons of microplastics in abrasive cleaning agents corresponds with our experience that it is hard to find abrasive cleaning agents with microbeads inside. The industrial use of products containing microplastics could not be verified.

To calculate the distribution of microplastics, the highest estimated usage of 2.6 tons/year was employed. The generic calculation method for emissions from wastewater to surface water, as explained in the previous chapter, has been followed.

The most relevant pathway for the emission of microplastics from abrasive cleaning agents is the pathway to the sewerage system.

Table 7 Overview of estimated microplastic emissions and uncertainties involved. Uncertainties in usage and removal efficiency in STP are included.

	Best estimate (tons/year)	**Range (tons/year)**
Total emission	2.6	2.4-2.6
Direct emission to surface water	0.008	0.007-0.008
Via sewage system to surface water	1.2	0.2-2.2
To sewage sludge	1.4	0.4-2.4

Almost all microplastics emitted from abrasive cleaning agents are discharged into the sewer: approximately 2.6 tons/year, half of which is assumed to reach the surface water. An almost negligible fraction of 0.008 ton/year is emitted directly to surface water; the rest is transferred to the sewerage system. As mentioned before, the uncertainties in removal efficiency in STP are high.

4 Paints and coatings

4.1 Introduction

Paints are applied for aesthetic reasons and for their protective qualities. Once applied and dried, paints protect substrates and prolong the lifetimes of bridges, metal and wooden construction materials, cars, furniture, etc.

Paints are made from a mixture of ingredients that originate from fossil, mineral, biological or synthetic sources. The resins (= polymers from petrochemical or natural oils) are the ingredients in an organic paint that hold all the pigment and fillers together, ensure the integrity of the paint-layer and create the adhesion to the substrate.

The majority of paint formulations do not have microbeads as an ingredient. Such beads are added to a small portion of the paint portfolio only to achieve some special characteristics. However, paint particles are described as microplastics because of the resin content.

The sanding of old paint layers or the degradation of the paint layer by weather conditions may lead to paint particles being released into the environment. The particles in such 'paint dust' will show a large variety in size distribution. Such particles are never discrete polymer particles or beads, but flakes of the paint-layer composed of the solid components in the paint. Which means a part is polymer and the remainder are minerals. Depending on the type of paint, the polymer content of these flakes may vary.

An entire paint flake is defined as a microplastic particle because of the polymer content (even though part of the particle consists of other substances). See Chapter 2 for more information on the definition of microplastics.

There is little knowledge about the potential emissions of microplastics resulting from the application of paints. Since the application of paints is an activity done by professionals, as well as by consumers (do-it-yourself), and it is done on a rather diffuse scale, there is a potential for significant emissions. In this chapter, we will provide a preliminary estimate of the emissions of microplastics from paint application as they occur during the entire lifespan of the coating.

Microplastics from paints can be released into the environment through tear and wear during use (weathering), during removal of old paint layers (sanding, abrasion), and through rinsing brushes and rollers. Figure 2 shows a microplastic of sanded paint. This was an alkyd lacquer, which was sanded manually with a fine grain. It shows that through sanding aggregated particles are formed with a size of approximately 20 µm. The aggregates are built up from smaller fragments, with sizes down to 1 µm.

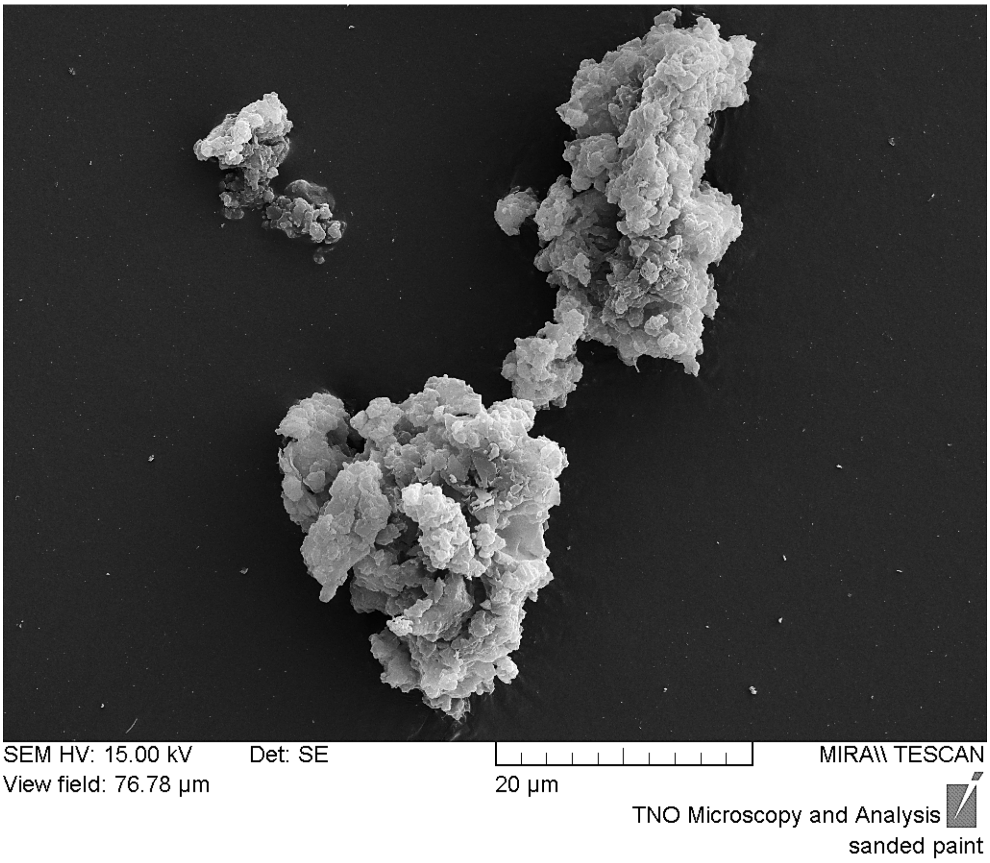

Figure 2 Microplastic of sanded paint.

The weathering of paint consist of a complex set of processes in which the combined action of ultraviolet (UV) light and oxygen are predominant. It causes the dissociation of chemical bonds and can lead subsequently to chemical changes, which ultimately disintegrates a polymer down to carbon dioxide. This is beyond the scope of this desk research, but might be relevant when considering the environmental fate of microparticles derived from coatings.

Paints consist of binders (polymers), fillers, pigments and solvents/water. After the paint has been applied, the solvents and water evaporate and the binders and fillers remain, together forming the solid content, part of which may be emitted as microplastics during its lifespan. Thus when the paint is applied and dried, the microplastic consists of the polymers and the fillers together, because the several components are stuck together in one particle. When the paint is not yet dried (such as when rinsing the brushes in the sink), the microplastic consists of the polymers only, because the several components are not yet stuck together in a single particle.

A first estimate of potential microplastic emissions has been constructed taking into account the (limited) information available from literature, expert judgement and estimations. During this study, valuable input and comments have been received from the industry through the cooperation of the VVVF (Dutch industry association for paint producers) and two workshops with industry experts representing large paint producing companies in the Netherlands.

4.2 Scope

Before starting to estimate the emissions of microplastics, it is crucial to ensure the boundaries of this study. Paints are used in many different sectors as protective and decorative coatings. The building and construction sector and the DIY (do-it-yourself) sector have been selected, as together they account for more than 70% of the total paint consumed in the Netherlands (see Figure 3). Additionally, we take into account shipbuilding and ship maintenance (nearly 10% of the paint consumed), because emissions to water are expected to be higher than in other sectors of paint users.

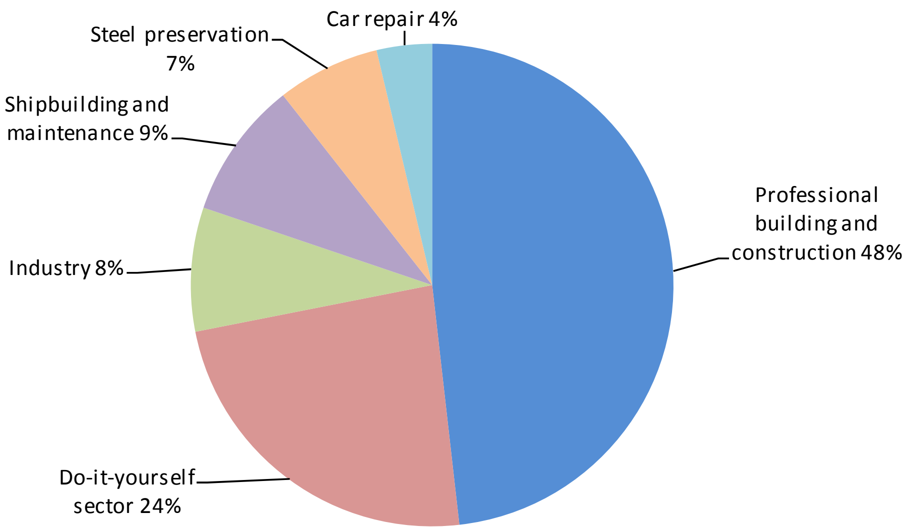

Figure 3 Domestic sales in the Dutch paint industry per sector in 2014 [27].

Three sources of emissions from microplastics have been identified which result in emissions to surface water:

- removal of old paint layers (including sanding and abrasive blasting);
- wear and tear of paints during their lifespan (largely due to weather influence);
- rinsing of paint rollers in the sink.

The emissions of microplastics from Building and Construction and DIY are presented in paragraph 4.3.1, and from the shipping sector in paragraph 4.3.2.

4.3 Calculation method

4.3.1 Building / construction and DIY sectors

4.3.1.1 Selection of paint products and processes

Emissions of microplastics into water are expected to originate from maintenance and from the wear and tear of exterior coatings. The microplastic emission into water from interior paint applications is assumed to be zero. Another source considered is the washing of brushes in the sink. We assume this is only done by DIY users, and only with (water-based) wall paints.

A schematic illustration of the emission sources considered in this study is shown in Figure 4.

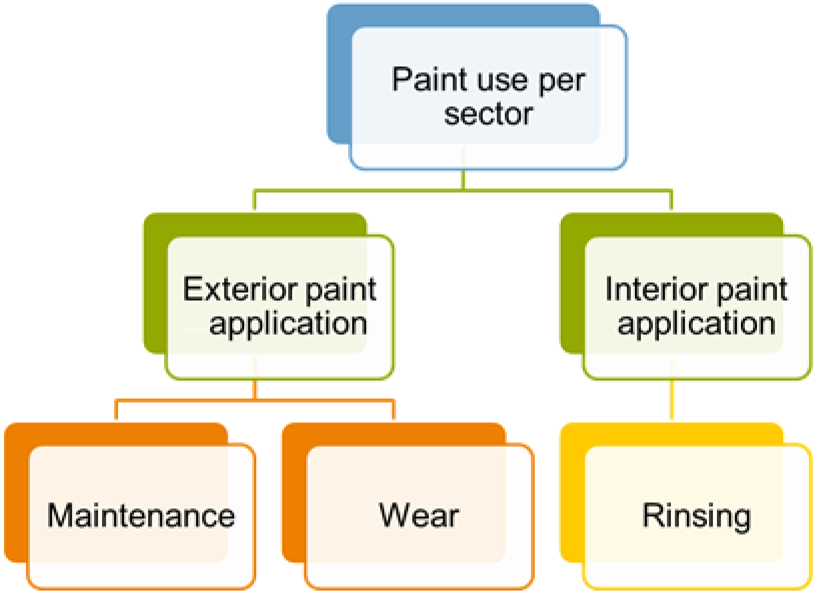

Figure 4 Processes included in the emission calculation

For this assessment, the VVVF has provided, in confidence, detailed sales volumes in the Dutch market for 2014 (in tons); separately for the professional and the do-it-yourself sector. The sales volumes were obtained from members and have been supplemented with an estimate of sales data from non-members. The following product groups are identified in these statistics:

1. Concrete (including repair products) *(only professional use)*
2. Lacquer, varnish, undercoats and primers
3. Wood stains
4. Wall paints
5. Plasters
6. Other paints (including road paints)
7. Paints used in pre-made wooden products (for instance window frames) *(only professional use)*

The product group 'Other paints' consist of road paints (only paint marking, but not thermoplastic marking) and several other products, such as cleaning materials, preparatory materials and products for painting, as well as floor coatings. Only the road paint marking is included in the estimation of microplastics from paints. The sales volumes for each of the product groups listed above form the starting point of the calculation presented in this chapter.

4.3.1.2 Overview of calculation steps

As stated above, the methodology to calculate emissions of microplastics starts from the estimated total sales data from VVVF-members (that is 161.2 ktons in 2014) and non-member companies in the Netherlands in 2014 [27]. The market share of VVVF member companies is approximately 90% (varies per product from 70 to 95%).

To estimate the emissions of microplastics from paint applications into water, the following approach has been followed (see Figure 4):

1. The paint consumption is first corrected for the amount that is not-used.
2. The paint consumption for both professional and DIY use is then divided among different product groups, i.e. concrete paints, lacquers, wood stains, etc. Seven product groups are identified in the professional sector and 5 product groups in the DIY sector.
3. The paint consumption for each product group is then split between interior and exterior application.
4. For the coatings applied to exteriors:
    a. Emissions resulting from maintenance (sanding and abrasive blasting) and emissions resulting from the wear and tear of the paint layer have been estimated. An abrasion test was performed to establish the amount of microplastics that can be released by abrasion.
    b. For each of the paints, the plastic content has been estimated by taking into account only the solid fraction of the paint.
5. For the coatings applied to interiors:
    a. Emissions resulting from rinsing brushes and rollers in the sink have been estimated for wall painting in the DIY sector only. For all other paints and for the professional sector, brush washing is assumed not to occur.
    b. For each of the paints, the polymer content has been estimated.
6. The total emissions are distributed over sewer systems and direct emission to surface water.

4.3.1.3 Emission from exterior paints

Based on the sales figures for paints, the emissions from the removal of old paint layers and from wear to the exterior paint application are calculated by applying the following formulas:

$$E_{removal} = \sum_{sector} \sum_{products} \left[Sales \times f_{sector} \times f_{product} \times f_{used} \times f_{exterior} \times f_{solids} \times EF_{removal}\right]$$

$$E_{wear} = \sum_{sector} \sum_{products} \left[Sales \times f_{sector} \times f_{product} \times f_{used} \times f_{exterior\_use} \times f_{solids} \times EF_{wear}\right]$$

whereby:

- *Sales* is the total paint volume sold
- f_{sector} is the fraction of paints sold to professional and DIY sector, resp.
- $f_{product}$ is the fraction of paint sold, specified by different types of paint. This is confidential information from VVVF.
- f_{used} is the fraction of sold paints that is used;
- $f_{exterior}$ is the mass fraction of the paints applied in an exterior situation for that product group;
- f_{solids} is the solid fraction in the paint for that product group;
- $EF_{removal}$ is the emission factor for the removal of the old paint layers, defined as the mass fraction of solid paint materials for the specific product group that is expected to be emitted as a result of these activities, taking into account the whole lifespan of the paint;

- EF_{wear} is the emission factor for wear, defined as the mass fraction of solid paint materials for the specific product group that is expected to be emitted as a result of wear to the paint layer, taking into account the whole lifespan of the paint.

Table 8 Input parameters for the calculation of microplastic emissions from exterior paint applications

Product group	f_{used}[1]	$f_{Exterior}$[2]	f_{solid}[3]	$EF_{removal}$[4]	EF_{wear}[5]
Professional use in the building and construction sector *F_{sector} =48%*					
Concrete paints	97%	50%	75%	0.0%	3%
Lacquer, varnish, undercoats and primers		40%	80%	3.2%	3%
Wood stains		25%	50%	3.2%	3%
Wall paints		7%	55%	0%	3%
Plasters		3%	55%	0%	3%
Other paints		10%	75%	0%	3%
Paints used in pre-made wooden products		25%	60%	3.2%	3%
Do it yourself (DIY) *F_{sector}=24%*					
Lacquer, varnish, undercoats and primers	85%	40%	65%	6.4%	3%
Wood stains		60%	20%	0%	15%
Wall paints		0%	55%	0%	3%
Plasters		0%	55%	0%	3%
Other paints		0%	65%	6.4%	3%

[1] In practice, not all the paints that are sold will be used. Especially in the DIY sector, typically some of the paints will remain in the can and these unfinished cans will be stored or collected through waste collection systems. The remaining paint will not result in any emissions of microplastics. We adopt the estimates of the OECD that say, for professional paints, 3% of the paints are not used [28], while for the DIY sector, a factor of 15% is taken based on a VVVF estimate between 10 and 16% (while OECD estimated 25%).

[2] The fraction of paint used for exterior applications is based on a study conducted on decorative paints for DG Environment [29], which has been complemented with information received from the paint manufacturers through the VVVF.

[3] The solid content is based on information obtained from the paint manufacturers, collected by the VVVF, and an average paint composition has been provided for this study for wall-paints, lacquers and primers. Additional data from the paint manufacturers has been collected by VVVF to distinguish between the paints used in the professional sector and those used in the DIY sector. The percentages provided in Table 8 are applicable to the paints used in exterior paint applications only.

[4] Before applying new paint layers, old layers are (partly) removed by sanding or abrasive blasting, as well as by burning-off of old paints layers. These techniques are mostly applied to wooden surfaces to remove the old paint layers before a new paint layer is applied. In an earlier study on microplastics conducted for Norway [30], an emission factor of 6.4% was used for emissions of microplastics from sanding and abrasive blasting. In the OECD study, from which this factor is taken, this factor was originally applied for the sanding and abrasive blasting of ship coatings, and assumed to be similar for other coatings [28].
In the Netherlands, the professional use of sanding and blasting equipment should come with dust extraction (existing regulations), which would take away nearly all emissions of small particles when applied correctly. This has been confirmed by the Dutch branch organization for maintenance in the building sector, OnderhoudNL. Other methods for the removal of paints are also applied, such as the stripping of paint layers through heat

and manual scraping of the paint. For these methods, it is more difficult to abate the emissions. In general, we expect that less abatement is used for DIY jobs than for those done by professional users.
Since no other estimates are available, we have chosen to keep the 6.4% emission factor for the DIY sector. A test has been conducted by paint manufacturers to quantify the emissions of solids from removal activities when using manual sanding. This was not a standardized test using a panel with two layers of paint, which was sanded manually with a fine grain. The percentage of emissions was found to be in the same range as the numbers presented in this section for DIY. However, assuming that the professional user will have more abatement measures in place, we estimate that emissions are 50% lower compared with DIY, so a factor of 3.2% has been adopted.
For wood stains, wall paints, plasters and other paints (professional), we assume no sanding or abrasive blasting takes place and therefore the emission factor is set at 0%.

[5] Emissions of microplastics resulting from the wear on paint layers are difficult to estimate. In Norway it was estimated that around 3% of the solid particles are weathered off during the lifespan of the paint [30]. This number is difficult to estimate, since it depends strongly on (amongst others) the influence of the weather. Discussions with experts provided a mixed picture: for exterior wall paints it may be too low, while for lacquers it may be too high. Since no alternative quantitative information was available, we have chosen to stick to the 3% emission factor for wear that was used in the Norwegian study [30]. Professional wood stains behave like lacquers and therefore the emission factor for professional wood stains is similar to lacquers. DIY wood stains are, by their nature, less durable. For wood stains applied in DIY (commonly used for gates and fences in residential gardens), we therefore assume a higher emission factor of 15%, as most of the layer is weathered off during the lifespan of the wood stains. This value was derived by assuming that the first two layers of wood stains were completely absorbed by the wood. Only the third layer is partly (assumption 50%) weathered.

4.3.1.4 Emission from interior paints

For interior applications, the emissions of microplastics are not taken into account, as these are assumed to be all (100%) collected as waste, which means no emissions into water take place. The only exception is the emissions from rinsing, which are assumed to take place only for wall paints in the DIY sector. Emissions from rinsing take place when paint rollers are rinsed in the sink after the paint has been applied. These emissions are calculated as:

$$E_{rinsing} = Sales_{DIY\_wall\_paints} \times f_{used} \times f_{polymer,DIY\_wall\_paints} \times EF_{rinsing}$$

whereby:

- $Sales_{DIY\_wall\_paints}$ is the total paint volume sold for wall paints in DIY (confidential data from VVVF);
- f_{used}= the fraction of sold paints that is actually used;
- $f_{polymer,DIY\_wall\_paints}$ is the polymer fraction in the paint for that sector (only the polymer and not the filling is taken into account, since the paint has not been applied yet);
- $EF_{rinsing}$ is the emission factor for rinsing, defined as the mass fraction of the amount of paint left in the roller before rinsing (assuming 100% is rinsed) compared with the total paint can contents.

Table 9 Input parameters for calculation of microplastic emissions from interior applications

Sector	Product group	f_{used} [1]	$f_{interior}$ [1]	$f_{polymer}$ [2]	$EF_{rinsing}$ [3]
Do It Yourself (DIY)	Wall paints	85%	100%	5%	1.6%

[1] See comments at Table 8.

[2] We assume that rinsing is only done in some cases in the DIY sector, and only for water-based wall paints. Alcrylate wood paints could also be rinsed with water, but this is used much less than with water-based wall paints. It is therefore assumed that all of the paint rollers from wall paints and none of the paint rollers from wood paints are rinsed. In the professional sector, the rollers and brushes are usually disposed of after the job. According to the VVVF, the polymer content of wall paints in the DIY sector is approximately 5%.

[3] The percentage of the paint that is rinsed is based on the assumption that paint rollers are rinsed 1 time per 10 litres of paint. A test was performed by a paint manufacturer that weighed the amount of paint that was left in the paint roller before rinsing it. Approximately 240 grams (160 ml) of paint was left in the paint roller, which means an emission factor of 1.6% of the paint. This percentage is in line with the percentage in the OECD emission scenario document [28] of 1.5%, and therefore we have used the 1.6% percentage in this study.

4.3.1.5 Emission into the sewer, surface water and soil

After the 3 emission sources ($E_{removal}$, E_{wear} and $E_{rinsing}$) have been quantified in terms of their total emissions of microplastics, their distribution to sewer (E_{sewer}) and surface water ($E_{surface\ water}$) is calculated.

In formula, these can be expressed as:

$$E_{sewer} = E_{removal} \times f_{sewer,removal} + E_{wear} \times f_{sewer,wear} + E_{rinsing} \times f_{sewer,rinsing}$$

$$E_{sw} = E_{removal} \times f_{sw,removal} + E_{wear} \times f_{sw,wear} + E_{rinsing} \times f_{sw,rinsing} + E_{sewer} \times (f_{effluent} + f_{untreated})$$

$$E_{soil} = E_{removal} \times f_{soil,removal} + E_{wear} \times f_{soil,wear} + E_{rinsing} \times f_{soil,rinsing}$$

whereby:

- E_{sewer} = emission of microplastics to the sewerage system;
- f_{sewer} = fraction of the microplastics that ends up in the sewerage system;
- $E_{removal}$ = emission from removal of old paint layers;
- E_{wear} = emission from wear of the paint layer;
- $E_{rinsing}$ = emission from rinsing;
- E_{sw} = emission of microplastics into the surface water;
- f_{sw}= fraction of the microplastics that is directly discharged into surface water;
- $f_{effluent}$ = fraction of microplastics in the sewerage system that ends up in the effluent (see also paragraph 2.3);
- $f_{untreated}$= fraction of microplastics in sewerage system that is not treated (see also paragraph 2.3).

In order to determine the fraction of paints that ends up in the sewer and/or surface water, a distinction is made between rural and urban areas, because these areas have different ways to deal with run-off water from paved surfaces. Moreover, the number of houses in urban areas is higher than in rural areas and the surface area that is painted is greater in urban areas. Note that emissions to the sewer will flow to wastewater treatment plants. Part of the microplastics will be removed from the wastewater and the effluents from the wastewater treatment plants will contain fewer microplastics. The purification rate of the wastewater treatment plants has not been a part of this study. Microplastics that are not emitted into surface water or the sewer, will remain in the soil. These emissions will not end up in surface water or the sewer.

Table 10 Input parameters for the calculation of microplastic emissions into sewers and surface water.

	Urban		**Rural**		**Overall value**
	$f_{sw,pav}$	f_{paint}	$f_{sewer,pav}$	f_{paint}	
Rinsing					
f_{sw} [1]					0.3%
f_{sewer} [1]					99.7%
f_{soil}		not relevant			0%
$f_{untreated}$ [1]					0.5%
$f_{effluent}$ [1]					45%
Maintenance and wear					
f_{sw} [2]	0%	66%	10%	34%	3.4%
f_{sewer} [2]	60%	66%	0%	34%	39.4%
f_{soil} [2]	40%	66%	90%	34%	57%
$f_{untreated}$ [1]					20%
$f_{effluent}$ [1]					36%

1 See paragraph 2.3 "Sewerage systems in the Netherlands"

2 In order to estimate how much paint was used in urbanized areas and how much in rural areas, the population density, the number of households and the average size of houses in these areas was used. The houses in urbanized areas are smaller than in rural areas, and therefore less paint is used in urban areas. We estimated the surface area of the outside walls of houses (see Table 11) and used this to allocate the amount of paint used in urban areas and in rural areas, respectively. It was estimated that 66% of the paints are used in urban areas, whereas 34% are used in rural areas. The overall $f_{sw,removal}$ and $f_{sw,wear}$ are calculated by: $f_{pav,urban} \times f_{paint,urban} + f_{pav,rural} \times f_{paint,rural}$., where f_{pav}, is the fraction of run-off water from paved surfaces that is transported to surface water in urban areas, and fpaint is the fraction of the paint that is used in urban and rural areas, respectively.

Table 11 Calculation of the surface area of the outside walls that need painting, which can be used as a weighing factor for the amount of paint used in urban and rural areas.

	Highly urban[1]	**Urban**	**Medium urban**	**Slightly urban**	**Rural**
Houses (x million) [2]	1.720	1.838	1.315	1.324	1.325
Sides of house that need painting [3]	2	2	3	3	5
Length of house sides (m) [4]	7.9	8.8	8.1	8.6	8.7
Average number of floors [5]	1.5	1.5	2.0	2.0	2.0
Height of one floor (m) [6]	3	3	3	3	3
Outside surface area that needs painting (m^2) (x million) [7]	122.8	145.3	191.8	204.3	347.8
Percentage of paint used				66%	34%

[1] Highly urban = >2,500 addresses per km^2; urban =1,500-2,500 addresses per km^2; Medium urban (1,000-1,500 addresses per km^2); Slightly urban (500-100 addresses per km2), Rural < 500 addresses per km2;
[2] Calculated from data on the number of residents and the number of residents per house in 2014, these data were retrieved from statline.cbs.nl;
[3] Assumption. Houses in highly urban and urban areas mainly consist of apartments and terraced houses and only two of the four sides of these houses need painting. Some of the houses in moderately urban and slightly urban houses are detached houses, for which all the sides need painting. Therefore it is assumed that, on average, three of the four sides of all houses in these areas need painting. Almost all of the houses in non-urban areas consist of detached houses, for which all of the four sides need painting, But since extension buildings are also often present, this is raised to five sides in the calculation;
[4] Calculated from the surface area per floor and the assumption that the houses are square. Surface area per floor was estimated from the number of houses per size class per municipality (from Statistics Netherlands, statline.cbs.nl);
[5] Assumption. More apartments are used in highly urban and urban areas and therefore the number of floors per house is fewer than in the other areas;
6 Assumption. Height of one floor is the same in all of the houses (3 metres);
7 Calculated by multiplying the number of houses, number of sides that need painting, length of the house sides, number of floors, and the height of one floor.

4.3.2 Shipping

4.3.2.1 Introduction

Emissions from paint particles occur during maintenance (at shipyards and marinas) and during use of the ships. Maintenance includes the sanding and abrasive blasting of the coating. Emissions that occur during use of the ships include the regular wear of the coating and occasional damage.

We focused on the hull of the ship in this study. Microplastic emissions from other parts of the ship have not been taken into account.

In the following paragraphs, emissions during maintenance and use are estimated. This is split into two parts:

1. Maintenance at shipyards and marinas (mainly professional marine shipping and inland shipping) is described in paragraph 4.3.2.2.

2. Emissions during shipping (use of the ships) are estimated in paragraph 4.3.2.3

Professional ships are mainly maintained in a shipyard. Three shipyards in the Netherlands have a roof, while the other shipyards are open. Several measures to reduce emissions are in place, such as the use of windshields, wet abrasion (and the water is collected and cleaned), and the use of fine nets. Measures are described in the ‘Modelregeling dok-/hellingvloerdiscipline’ (=model regulation for good housekeeping of the dock and the slipway floors).

Most of the recreational ships are maintained at a marina. The ships are hauled out of the water and can be maintained by the ship’s owner. Maintenance can take place in the open air, but the owners are obliged to collect the sanded coating. Yet a part of the coating will still be released into the water because the sanding takes place in the open air, near the water.

Emissions from both sources are estimated based on the amount of coating applied to the ships multiplied by an emission factor.

Emissions during shipping (use of the ships) are estimated based on the amount of coating applied to the ships multiplied by an emission factor.

4.3.2.2 Emissions from shipyards and marinas

Ships used for marine shipping and inland shipping are maintained in shipyards. The Netherlands counts 12 shipyards for the maintenance of inland and marine ships, where approximately 1,250 ships are treated per year (information Netherlands Maritime Technology Institute (NMT). The underwater part is treated more frequently than the dry part of the ship’s hull. The underwater part is usually 4-6 metres high.

Coatings from ships are (partly) removed once every 3-5 years by sanding or abrasive blasting. During sanding or blasting, paint particles could be released into the water. Since 1985, several abatement measures have been implemented to reduce the emissions of paint and emissions of VOC into the air by applying ‘good housekeeping’. Therefore, only some of the paint particles are released into the environment.

Most of the recreational ships are maintained at a marina. The ships are hauled out of the water and can be maintained by the ship’s owner. Maintenance often takes place in the open air and the owners are obliged to collect the sanded coating. Yet a part of the coating will still be released into the water because the sanding takes place in the open air, near the water.

In practice, the ships are maintained every year for minor repairs. Complete replacement of the topcoat occurs less often (every 5-10 years) and replacement of the complete coating occurs even less often. This can occur in the open air, near the water.

The amounts of coating applied are used as a basis for the emission calculations. A percentage of the sold paint is released into the water during maintenance. Emissions are calculated using the following formula:

$$E_{removal} = (Use_{coating} \times f_{removal} \times (1 - f_{collected}))$$

whereby:

- $Use_{coating}$ is the amount of coating applied in ten years (in tons);
- $f_{removal}$ is the fraction of paint removed during maintenances;
- $f_{collected}$ is the fraction collected according good environmental practice;
- defined as the mass fraction of solid paint materials that is expected to be emitted as a result of these activities.

Table 12 Input parameters for the calculation of microplastic emissions from coating removal from marine and inland ships at shipyards

Sector	$Use_{coating}$[1] **(tons/year)**	$f_{removal}$[3]	$f_{collected}$[3]	**Overall EF**[4]
Professional ships	8,898[1]	40%	97.5%	1%
Recreational ships	354[2]			5%

[1] In 2014, around 9.2% of the Dutch paint sold was being used in the construction and repair of ships, as shown in Figure 3 [31]. The total paint sales was 161,200 tons, therefore the paint sales for construction and repair of ships was 14,830 tons. This includes the paints for professional marine and inland shipping. Paints for recreational boats are not included in this number. The solids content of these paints was 60% (based on the solids content published in product data sheets by International Paint (www.international-marine.com).

[2] The coating consists of a few layers of primer and a few layers of antifouling paint (under the water) or a topcoat (above the water). The amount of antifouling paint on recreational ships can be estimated based on the number of vessels (166,385 vessels in 2013), the antifouling paint use (2-2.25 litres per vessel per year) and antifouling paint weight (1-1.3 kg/litres) as mentioned in the factsheet on coatings from recreational boats [32]. Combined with a solid content for the coating of approximately 50%, this results in an antifouling use of 177 tons of antifouling paint per year. For the amount of primer and the amount of topcoat, no data are available. Based on average application volumes from several product sheets, we estimate that the amount of primer and topcoat equals the amount of antifouling paint used.

[3] In a Dutch environmental protocol for metal and electrotechnical industries (FO-industrie, 2007), it is indicated that since 1985 many measures have been implemented to reduce the emissions of paint and the emissions of VOC into air by applying good housekeeping [33]. In Appendix 5 of this report, it is estimated that the emissions have already been reduced by 95%, compared with the emissions in 1985. A large part of the emissions were reduced by collecting the abrasive material and the paint as waste and by collecting the wastewater. Even before 1985, waste from blasting was collected, which means that the emission in 1985 was less than 100% of the blasted material. It was common practice in 1985 to clean up the majority of residues from the dock floor and slipway [33]. Therefore it is assumed that the collection rate in 1985 was 50%. An extra reduction of 95%, compared with 1985 would result in an emission of 2.5% of the blasted material. The OECD report [28] reports an estimated emission of 5% from the maintenance of ships. Based on the information above, it is expected that emissions in shipyards will be lower. Given the fact that not all of the coating will be removed from the ship's hull during maintenance, a removal of 40% is assumed.

[4] For recreational marinas, an emission of 5% is estimated by OECD [28]. This value was reported for the marine industry by professional users, but it is expected that emissions in shipyards will be lower (see paragraph 4.3.2.2) in the Netherlands, because additional regulation (mitigation measures) have been implemented. For shipyards, the overall emission factor is therefore calculated as $f_{removal} \times (1 - f_{collected})$, resulting in an overall emission factor of 1%.

4.3.2.3 Emissions during the use of ships

There are several types of coatings used for marine shipping, inland shipping and recreational boats:

1. Hard coating. The biocide is released slowly by leaching, but the binder remains on the ship's hull;
2. Self-polishing coatings. The biocide is released by the (controlled) dissolving of the coating, and therefore the binder is also released into the water;
3. Non-stick coatings. Biofouling cannot stick to these coatings (if the ship sails fast enough).

Both the hard coatings and the non-stick coatings do not wear much. The polymers remain on the ship's hull and are not released into the water. Emissions from these coatings only occur from occasional damage.

Self-polishing coatings are designed to wear slowly. Self-polishing coatings react with sodium ions in seawater and this causes the release of the biocides and the soluble polymer molecules[1]. Since the polymers are soluble, the emissions of these microplastics are not included in the emission estimate of microplastics from coatings.

Since the polymers released during the reaction process of the self-polishing coatings are not included in the emission estimate, the emissions are only estimated for occasional damage of the coatings.

Exact details on the total amount of coating applied and the emissions during use are unknown. Emissions are estimated using the following formula:

$$E_{shipping} = (Use_{coating} \times EF_{wear})$$

whereby:

- $Use_{coating}$ is the amount of coating applied in one year (tons);
- EF_{wear} is the emission factor for wear of the paint layers, defined as the mass fraction of solid paint materials that is expected to be emitted as a result of these activities.

Table 13 Input parameters for the calculation of microplastic emissions from wear in professional shipping and recreational ships

Sector	**$Use_{coating}$ (tons/year)[1]**	**EF_{wear}[2]**
Professional shipping	8,898	1%
Recreational ships	354	1%

[1] The amount of paints used for professional shipping equals the amount of paint that is annually sold, according to the VVVF statistics, multiplied by the solids content of 60% (see paragraph 4.3.2.2). The amount of paints used in one year for recreational shipping equals the amount of paint that is applied in one year.

[2] Regular wear and tear on ship coatings and occasional damage of the coatings is included in the emission calculation of microplastics. An emission estimate of 1% is estimated during in-service use by the OECD [28]. Wear to self-polishing, anti-fouling coatings is not included, because this concerns water-soluble polymer molecules [34] [35].

[1] Most of the polymer molecules are soluble, but a very small part of the coating may consist of insoluble polymers. Information about the exact composition of the coating is not available and therefore it is assumed that all of the polymer is soluble.

4.4 Estimated emissions

4.4.1 Building, construction and DIY sectors

Based on the methods described in the previous paragraphs, total estimated microplastic emissions from the paints used in the building/construction and DIY sectors combined are approximately 490 tons.

Figure 5 shows the contribution of professional and DIY sectors to the total emission of microplastics from paint applications. The professional sector has higher emissions, which can be explained by a higher paint consumption than in the DIY sector and a relatively higher fraction of paints applied in exterior situations. Also, on average the solid content of lacquers, varnishes, undercoats and primers is higher in the professional sector (based on information from the VVVF).

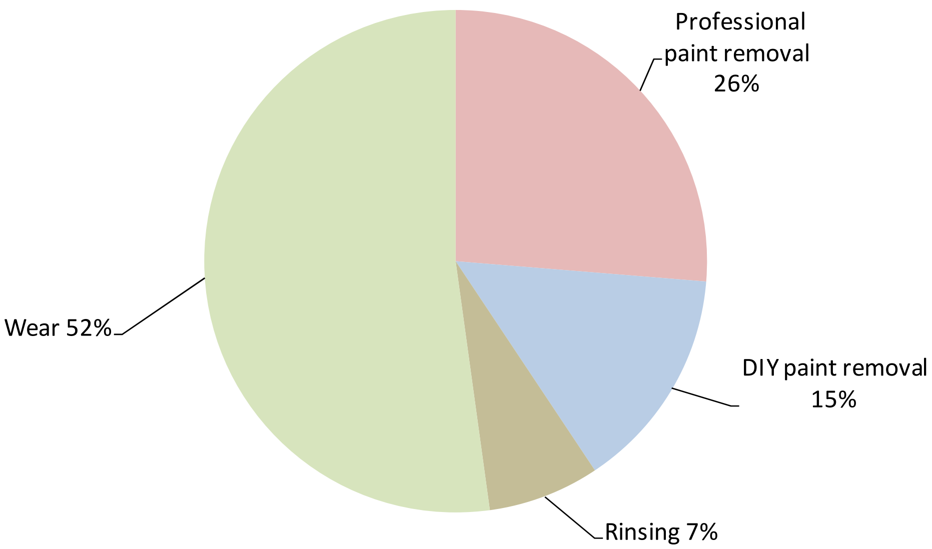

Figure 5 Contribution of professional and DIY activities to microplastic emissions from paints used in the building sector.

Emissions originating from the removal of paints are estimated to be 210 tons, the wear of paint adds 260 tons of microplastics and the rinsing of rollers contributes 16 tons of microplastics. An overview of the results is provided in Table 14.

Table 14 also presents an overview of the distribution of the emissions over different environmental compartments. More than half of the microplastics from paint end up in soil. Through wind and water erosion, paint particles in the soil may finally reach surface water. This pathway from soil to surface water has not been quantified here. The input to surface water amounts to approximately 126 tons of microplastics, 16 tons of which enters directly and 110 tons enters the surface water via the sewerage system. The emission from sewage to surface water depends on the type of sewerage system and the efficiency of the STP to retain/filter the microplastics. Note that the resulting emissions presented here have significant uncertainties, since limited information was available to underpin the different fractions and emission factors.

Table 14 Distribution of microplastics from paints applied in the building and DIY sector to different environmental compartments (tons/year).Totals are rounded to the nearest decade.

	Surface water		Sludge	Soil	Total
	Direct	*Via sewerage*			
Removal of old paint layers	7	45	36	117	**210**
Wear of paint layers	9	58	46	151	**260**
Rinsing paint rollers	0.05	7	8	0	**16**
Rounded total (tons/y)	**20**	**110**	**90**	**270**	**490**
(range)[1]	**7-37**	**22-387**	**14-343**	**113-626**	**205-1125**

[1] Ranges are the result of assuming 10% more or less paints used outdoors, and two times higher or lower emission factors for abrasion or wear, in combination with a removal efficiency in the STP of 10-90%.

Uncertainties in the assessment are reflected by the ranges, estimated total microplastic emissions can be approximately a factor of 2 higher or lower. The uncertainty range is calculated by assuming:

1. A factor of 2 in the uncertainty range of the emission factors for wear and removal of old paint layers;
2. 10% variation in the interior and exterior application for the sector lacquer, varnish, undercoats and primers for both professional and DIY sectors;
3. For rinsing, we have assumed a factor of 2 in uncertainty for the emission factor.

Uncertainties in the distribution are up to a factor of 10. The removal efficiency in STP, especially, causes high uncertainties.

4.4.2 *Shipping*

Emissions to surface water from coatings have been calculated for maintenance (in shipyards and marinas) and during use of the ships. The total estimated microplastic emission from the paints in the shipping sector is approximately 200 tons. A summary of the emission estimates is presented in Table 15.

Table 15 Emissions from maintenance and during use (wear) of marine and inland shipping (in 2014) and recreational shipping (in 2013) (tons) to surface water.

	Maintenance	Wear	% of used paint
Professional shipping	89 (44-178)	89 (30-267)	2%
Recreational shipping	18 (6-53)	4 (1-11)	6%
Total	107 (50-231)	93 (31-278)	

Emissions are mainly caused by marine and inland shipping. Emissions during maintenance and during the use of ships are similar. Only for recreational shipping, it is estimated that maintenance is causing higher emissions than wear for the ships.
It needs to be mentioned that the resulting emissions presented here have significant uncertainties, since limited information was available to underpin the different fractions and emission factors.
Table 15 presents the resulting emissions with an uncertainty range for total emissions. The uncertainty range is calculated by assuming:

- A factor of 2 in the uncertainty range for the emission factors for the removal of old paint layers in shipyards;
- A factor of 3 in the uncertainty range for the emission factors for the removal of old paint layers in marinas;
- A factor of 3 in the uncertainty range for the emission factors for the weathering of paint layers during use.

4.5 Uncertainties

The current assessment provides a rough estimate of microplastic emissions from paint applications. Information obtained from literature, experiments, as well as information provided by VVVF was used to make the assessment as realistic as possible. Still, the assessment could be further improved by collecting experimental data on:

1. the fraction of paint that is removed during maintenance;
2. the fraction of paint residues that are collected on marinas and shipyards;
3. the fraction of paint released during use (wear) of the ship.

Norway has also estimated the emissions of microplastics from paints (and several other emission sources) [30]. The total annual emission of polymers from paints used by construction and shipping in Norway was 1,230 tons, which is considerably higher than the estimates from the Netherlands. This is caused by 1) the different volumes of paint used and 2) the different emission factors and 3) calculation with either the polymer fraction or the solid content fraction.

The Norwegian approach, if applied to paint sales data in the Netherlands, would lead to higher emissions in the Netherlands (1,300 tons/year, 960 tons/year of which are from shipping and 360 tons from construction). The differences are caused by the higher emission factors in the shipping sector used in the Norwegian approach, and the consideration of the polymer fraction only, whereas in the Netherlands the total solid fraction was taken into account. The different emission factors can be justified because our assessment uses sector-specific information and information about common practices in the Netherlands. The lower emissions from paints in the shipping sector in the Netherlands can be explained by the implementation of a number of measures. In the Netherlands, all of the shipyards collect and purify wastewater, while in Norway, only a few shipyards have water treatment systems [30]. Therefore, in Norway an emission factor of 22% was employed (which is two times higher than the value recommended by OECD), whereas emission factors of 2% for professional shipping and 6% for recreational shipping are employed in the Netherlands. See description at Table 12, footnote 3).

5 Rubber tyres

5.1 Introduction

City dust in urban runoff is known as a significant source of pollution to waterways. A substantial portion of the constituents of city dust comes from polymer-based material such as tyres, which is considered to be microplastic. Researchers studying storm water runoffs from Norwegian and Swedish cities found that they are substantial sources of a wide range of traffic-related pollutants [36, 37].

Road traffic contributes significantly to fine particulate matter in air, which is usually expressed as particles smaller than 10 μm (=PM10). PM stands for Particulate Matter, the number indicates the upper limit of the particle size (diameter) in micrometres. In the Netherlands, fine particulate exhaust emissions into the air from road transport show a decreasing trend since1990 [39].The contribution of road-traffic-related non-exhaust emissions (wear) to total PM10 emissions in the Netherlands is approximately 10%, an estimated 35% of which is caused by tyre wear, 20% by brake wear and 45% by road wear (www.emissieregistratie.nl).

Fine particulate matter has been associated with adverse health effects through inhalation [38]. These emissions are therefore being targeted through increasingly stringent European emission standards. These policies succeed in reducing exhaust emissions, but do not address "non-exhaust" emissions from tyre wear [39, 40]. Additionally, particles emitted into the soil and water cause the leaching of metals, PAHs and other potentially toxic additives, which are shown to have adverse effects on aquatic ecosystems [41, 42]. Yet other studies indicate that the critical levels at which effects on aquatic or sediment-dwelling organisms can be expected are higher than the concentrations currently present in these compartments [43, 44]. It is beyond the scope of this study to perform an ecotoxicological risk assessment on tyre wear. This would require a thorough evaluation of the reliability and usefulness of these studies and other literature on this topic.

The total amount of tyre tread material (PM10 and larger particles) lost per kilometre varies widely and depends on several parameters such as: a) tyre characteristics, with the most significant being size (radius/width/depth), tread depth, construction, pressure and temperature, contact patch area, chemical composition, accumulated mileage and alignment; b) vehicle characteristics such as weight, distribution of load, location of driving wheels, engine power, electronic braking systems, suspension type and state of maintenance; c) road surface characteristics, with the most significant being material (asphalt/concrete), texture pattern and wavelength, porosity, condition, wetness and surface dressing; d) vehicle operation, such as speed, linear acceleration, radial acceleration, frequency and extent of braking and cornering.

Road transport vehicles are also a source of other pollutants, due to the emission of particles via their exhaust gases and via the wearing processes of vehicle parts. Owing to the introduction of cleaner technology for diesel/petrol transport vehicle engines and the increasing – but still limited – share of electrical or hybrid vehicles, the contribution of exhaust gases to the total emission of transport vehicles has decreased.

5.2 Characterization of microplastics from road vehicle tyres

Road vehicle tyre tread mainly consist of natural and synthetic rubber (SBR/BR styrene-butadiene rubber and butadiene rubber). SBR is derived from two monomers – styrene and butadiene. The mixture of these two monomers is polymerized by two processes: from solution (S-SBR) or as an emulsion (E-SBR). The styrene/butadiene ratio influences the properties of the polymer: with high styrene content, the rubbers are harder and less rubbery [45].

The exact composition largely depends on the application/requirements: passenger cars have E and L-SBR/BR blends as the main tread component, whereas truck tyres have natural rubber (in some cases as a BR blend) as the main component [46]. Table 16 shows the composition of passenger cars in the European Union.

Table 16 Composition of passenger car tyres in the European Union [46].

Passenger car tyres	Market-weighted average (kg/tyre)
Synthetic rubber	2.14
Natural rubber	1.46
Carbon black	1.54
HD silica	1.00
Sulphur	0.09
ZnO	0.13
Stearic acid	0.055
Accelerators and vulcanization agent	0.079
Anti-degradants	0.13
Cobalt salts	0.016
Steel	1.03
Rayon	0.093
Reinforcing resins	0.081
Nylon	0.11
Plasticizers	0.58
Polyester	0.17
Silanes	0.093
Total reference tyre weight (kg)	8.79

The composition of tyre tread is different from the whole tyre as shown in Table 16: a typical tread consists of 50% rubber polymers with reinforcing and softening fillers (25 and 20% respectively) (as tread weight%) [47]. Other minor tread components are activators (ZnO), softener (stearic acid), vulcanizers (S), accelerators and antioxidants. As mentioned earlier, the exact composition will also largely depend on vehicle type. The older tyre tread information may also not be relevant anymore these days, since innovations are ongoing [48]. A recent study [49] also mentions that exact details on tyre composition are absent for commercial reasons. It also mentions blends of different rubber (41%), fillers (30%) and reinforcing materials (15%) as main components. The bulk of tyre tread contains a variety of rubbers, including natural rubber co-polymers (NR), poly-butadiene rubber (PBR), styrene-butadiene rubber (SBR) and other rubber compounds. The general composition of the rubber blends commonly used in passenger vehicles is further specified: natural rubber (40%), styrene-butadiene rubber (30%), butadiene rubber (20%) and other rubber (10%). Fillers are added to the rubber in order to improve its strength characteristics in terms of hardness and wear resistance. Carbon black has been commonly used as filler, but recently it has been partially substituted by other materials (silica incorporated with a silane coupling agent, carbon-silica dual-phase filler (CSDP) and "nanostructure" carbon blacks) in attempt to decrease rolling resistance without compromising strength and longevity.

Particles generated during the use of a tyre are always a mixture of the road pavement and the tyre. For this reason, they are called Tyre and Road Wear Particles (TRWP). TRWP are generated from the friction produced at the pavement/tread surface interface during rolling of the tyre and are considered as non-exhaust traffic-related emissions. The size, composition and fate of TRWP is the result of a complex process that is highly influenced by several factors (such as friction, tyre type, road pavement characteristics, wearing and weather conditions.
Table 17 shows an example of the differences between road particles, tread wear particles and tread particles. The wear generated in a laboratory set-up comprises tyre and asphalt particles – under outdoor conditions, dirt and residues of brakes may also be included. In this report, the emission estimates are based on tyre weight loss during its lifetime and thus reflect the tyre wear fraction only. Particles released from the road surface are not included.

Table 17 General composition analysis of particles as determined by thermogravimetric analysis (% mass. [50].

	Outdoor tyre and road wear particle (RP)[1]	**Laboratory tyre and road wear particle[2]**	**Tread composition[3]**
Plasticizers and oil (%)	13	10	19
Polymers (%)	23	16	46
Carbon blacks(%)	11	13	19
Minerals(%)	53	61	16

[1]Tyre and road wear particles: collected during outdoor driving, which contain contributions from tyres, as well as other sources (i.e. fuel, brakes, pavement, atmospheric deposition, etc.);
[2]Tyre wear particles: collected on a simulated laboratory driving course;
[3]Tread particles: cryogenically ground from pieces of unused tread.

All tyre tread wear by road vehicles was considered to be microplastics, since the particulates partly consist of rubber polymers [30]. Tyre wear in road traffic causes an emission of tyre particulates, comprising fine particulate matter (PM10, PM2.5), coarse particulate matter and components such as metals (in particular zinc) and PAHs. The current proposal for the definition of microplastics includes composite particles containing a certain amount of polymers as microplastics [7]. A cut-off value for a minimum polymer content has not yet been decided on.

Tyre and road wear particles obtained from a tyre-road abrasion experiment are shown in Figure 6. The density of tyre and road wear particles is approximately 1.2-1.3 g/cm^3. The density affects the distribution of the particles in the environment. Because the particles are heavier than water, they tend to sink to the sediment. In situations with high flow velocities and turbulence, the particles are present in the water phase as suspended matter.

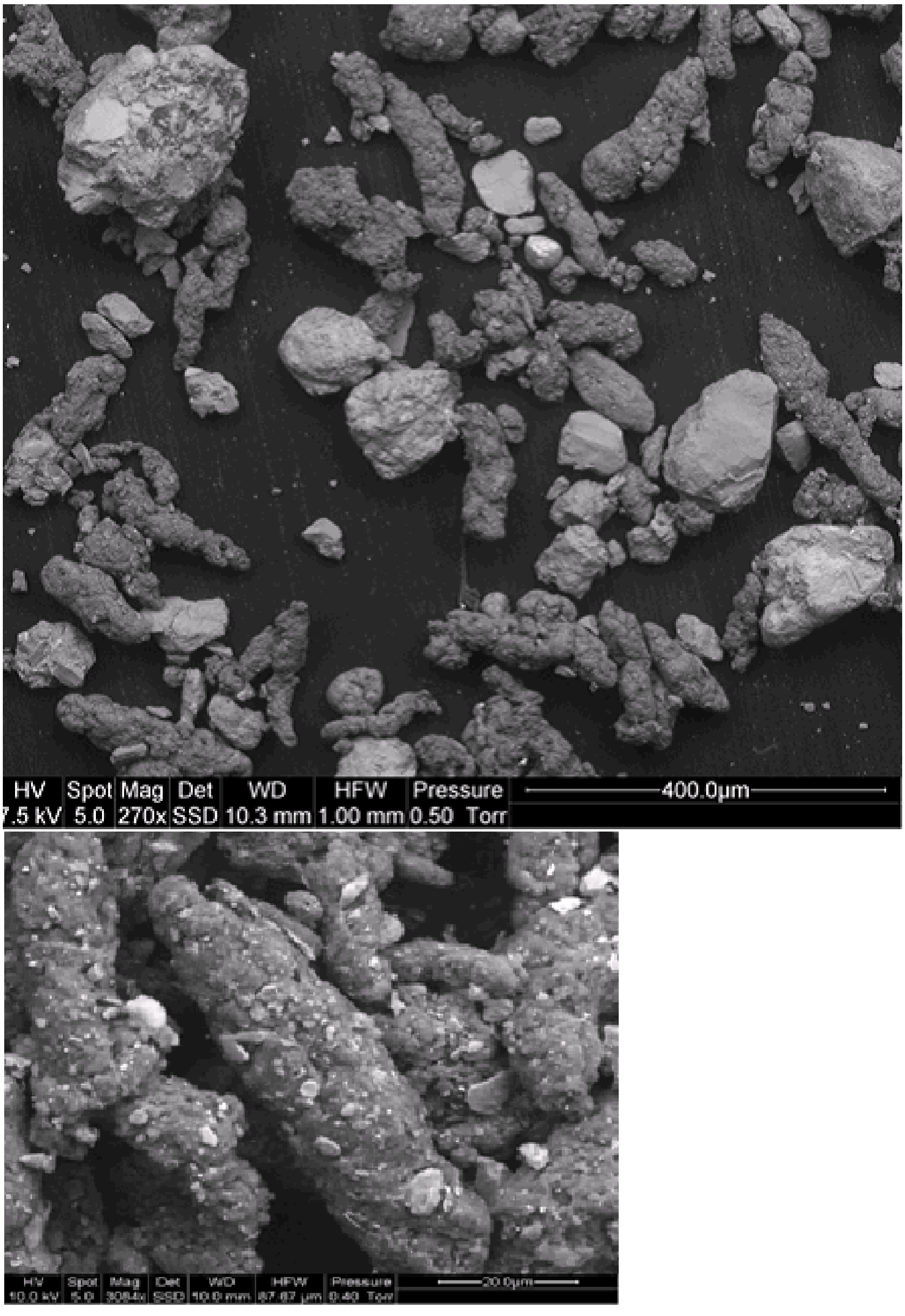

Figure 6 Tyre and road wear particles generated by road contact in a realistic outdoor situation (pictures provide by NVR/ETRMA with permission from Michelin). The dark-coloured material is predominantly car tyre material, whereas the light-coloured particles are road residues. Pictures are photographed at different magnifications.

Generally, it can be stated that wear particles that are emitted into the soil, surface water and sewer will have an approximate range of between 10 and 400 µm. The study mentioned in Table 17 also gives information on the particle sizes of tread wear [50]. Two more recent studies [48, 49] refer to this and other publications. Tyre wear contributes to airborne particles (PM10 5-10% of total tyre wear), but most wear particulates generated by mechanical processes are larger. Yet fine and ultrafine particles may also be generated by thermo-mechanical and thermo-chemical processes. The particle size of tread wear particles may range from less than 10 µm up to several hundred µm. The size of the particles, however, largely depends on characteristics during wearing. A bimodal distribution based on particle numbers, generated in a road simulator laboratory, was shown to have peaks at 5 and 25 µm (range 4-350 µm) [50]. For particles collected during driving on the road showed a similar range, but unimodal distribution for particle numbers was found with a mode of approximately 25 µm.

5.3 Calculation method

The relevant pathways for the emission of microplastics from tyres are into the air, soil, sewerage system and directly into surface water.

For the estimation of the microplastic emissions, the data set for 2012 and the method of the Dutch Pollutant Release and Transfer Register (www.prtr.nl) was used [51].

Tyre wear emissions depend on the total distance that vehicles have driven. The type of road (e.g. the presence of ZOAB) and the vehicle type also have an effect. The total distance covered on the road in 2012 was 132,785 million kilometres, almost 50% of which was covered by highway traffic (Table 18). Passenger cars were responsible for 78% of the total coverage (103,122 million km, Table 19).

Table 18 Total number of vehicle kilometres (vkm) and percentages of road coverage in the Netherlands in 2012.

	Road type			
Urban	**Rural**	**Highway**	**Total**	
26,755	45,479	60,551	132,785	x 10^6 km
20	34	46	100	%

The total emission E_{sw} of tyre tread particulates to surface water is calculated as the sum of the direct emission to surface water, the indirect emission through untreated sewage, and the indirect emission through treated sewage.

Because part of the traffic tyre wear emissions will consist of airborne pollutants, a correction with f_{air} is applied. Total emissions of tread wear are calculated by multiplying an activity rate (AR), in this case the number of kilometres driven on Dutch roads, by an emission factor (EF), expressed in emission per million kilometres. To calculate the emissions of wear microplastics into the soil, surface water and the sewerage system, several other factors are applied, such as the effect of road type, distribution to environmental compartments, efficiency of removal at sewage treatment plants.

The three pathways $E_{direct\ to\ sw}$, $E_{treated\ to\ sw}$ and $E_{untreated\ to\ sw}$ are expressed below:

$$E_{sw} = (1 - f_{air}) \times \sum_{road\ type} f_{sw} \times f_{pav} \times \sum_{vehicle\ type} AR \times EFwear$$

$$E_{sewer} = (1 - f_{air}) \times \sum_{road\ type} f_{sewer} \times f_{pav} \times \sum_{vehicle\ type} AR \times EFwear$$

$$E_{soil} = (1 - f_{air}) \times \sum_{road\ type} f_{soil} \times f_{pav} \times \sum_{vehicle\ type} AR \times EFwear$$

whereby:

- E_{sw} is the total emission of tyre tread particulates to surface water (tons/year);
- E_{sewer} is the total emission of tyre tread particulates to sewer (tons/year);
- E_{soil} is the total emission of tyre tread particulates into the soil (tons/year);
- f_{air} is the fraction of tyre tread particulates emitted into the air (fraction PM10) and is used to calculate the amount of coarse particulates (≥PM10) emitted into the soil, surface water and/or sewer;
- road type: urban, rural or highway;
- vehicle type : see Table 18;
- f_{pav} is the fraction of car tyre wear that is available for run-off to adjacent soil and surface water and sewer, it is a correction for entrapment in the road;
- f_{sw} is the fraction of coarse particulates emitted directly to surface water, depending on road type;
- f_{soil} is the fraction of coarse particulates emitted into the soil, depending on road type;
- *AR* is the activity rate per road type per vehicle type expressed as traffic performance: distance covered on Dutch road network per road type (mln km);
- f_{sewer} is the fraction of coarse particulates emitted to the sewerage system, depending on road type;
- $EFwear$ is the emission factor of tyre tread wear particulates per vehicle type per road type (mg/km); this is the estimated emission factor based on both tyre tread loss measurements (mass reduction) and expert judgement [51]. It concerns the contribution of the tyre to TRWP with approximately 23% polymers (see Table 17).

Table 19 gives an overview of the input parameters used for calculating the emission of tyre wear microplastics in the Netherlands in 2012. Most of the parameters are taken from the method for calculating the emissions of transport in the Netherlands [51].

Table 19 Input parameters used for the calculation of emissions of tyre wear particulates to surface water in 2012 (AR: million vkm (vehicle kilometres); EF_{wear}: mg/vkm). Values shown are rounded off.

Road type	Vehicle type	$AR_{,j,}$	$EF_{wear,}$	f_{pav}[1]	f_{air}[2]	f_{soil}[2]	f_{sw}[2]	f_{sewer}[2]
Urban	Moped	1,608	13	1	0.05	0.4	0	0.6
	Motorcycle	393	60					
	Passenger car	20,959	132					
	Van	2,670	159					
	Lorry	412	850					
	Truck	277	658					
	Bus	354	415					
	Special vehicle (light)	22	159					
	Special vehicle (heavy)	59	850					
Rural	Moped	690	9	1	0.05	0.9	0.1	0
	Motorcycle	1,100	39					
	Passenger car	36,622	85					
	Van	5,331	102					
	Lorry	533	546					
	Truck	876	423					
	Bus	207	267					
	Special vehicle (light)	44	102					
	Special vehicle (heavy)	76	546					
Highway	Moped	0	10	0.12	0.05	0.9	0.1	0
	Motorcycle	1,089	47					
	Passenger car	45,541	104					
	Van	8,649	125					
	Lorry	1,453	668					
	Truck	3,455	517					
	Bus	82	326					
	Special vehicle (light)	72	125					
	Special vehicle (heavy)	210	668					

[1] In 2012, a factor for the entrapment of non-airborne particulates in ZOAB on highways of 0.1165 was applied (based on a 93% ZOAB share and entrapment of 95%).

[2] Based on literature on tyre tread wear and particle sizes. Airborne PM10-emissions show a large variation: 5% of total tread wear was selected for airborne PM10-emission. The remaining larger wear fraction is assumed not to emit to air and is divided over the other compartments of soil, surface water and sewerage system. This division over compartments [20] is mainly based on expert judgement.

5.4 Estimated emissions

The results of the calculation using the input data from Table 19 are shown in Table 20. The calculated total tyre tread wear for 2012 was 17,300 tons, 900 tons (5%) of which was emitted as airborne particulates (PM10). A total of 500 tons of tread wear was emitted directly into surface water (from rural roads and highways) and 2,300 tons into the sewerage system (from urban roads). For the indirect emissions into surface water after treatment in a wastewater treatment plant, further research into removal efficiency is required. Other contributions to the final load of surface water, such as the run-off from soil and the deposition of airborne particulates, are not included. They are estimated to be less relevant contributors.

Table 20 Emission of tyre tread microplastics per road type and environmental pathways in the Netherlands in 2012 (tons/year). Values are rounded to the nearest hundred tons.

Road type	**Captured road residue[1]**	**Air**	**Soil[2]**	**Surface water**		**Sludge**
				Direct	Via sewerage	
Urban			1,500	0	1,300	1,000
Rural			3,800	400	0	0
Highways[1]	7,400		900	100	0	0
TOTAL	**7,400**	**900**	**6,200**	**500**	**1,300**	**1000**
range					600-1,900	300-1,600

[1] Highways contribute to emissions into the soil, surface water and sewer only to a limited degree, since the emission of coarse particulates into the environment on this road type is greatly reduced by the widely used open asphalted concrete in the Netherlands (Porous asphalt; ZOAB in Dutch).

[2] The emission of tread particulates into soil in 2012 was calculated to be 6,200 tons, which results in a total of 900 tons of non-airborne particulates (excluding captured road residue). The highest emission into soil is calculated for rural areas (3,800 tons).

The fraction of urban car tyre tread wear that is emitted into the sewer has the potential to reach surface water (1,300 tons) or to be retained in the sewage sludge (1,000 tons), depending on the removal efficiency and the type of sewerage system. Because reported removal efficiencies are variable, the uncertainties are reported as well. Removal efficiencies between 10 and 90% were used to calculate the range of tyre wear particles in effluent and sewage sludge (more details are provided in paragraph 2.3).

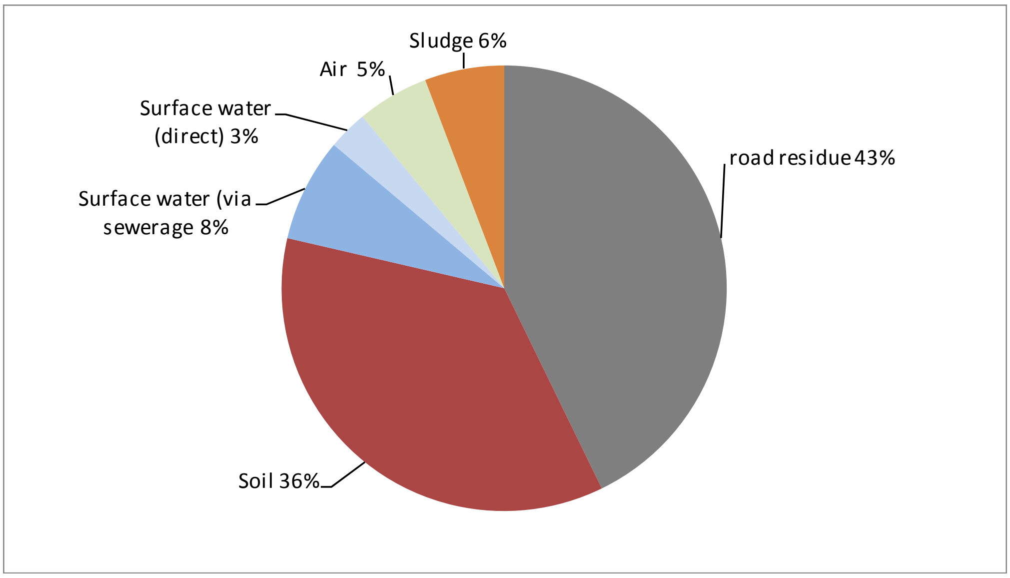

Figure 7 Distribution of car tyre wear (percentages) amongst environmental compartments.

5.5 Uncertainties

In order to improve the underpinning of the emission estimates and reduce uncertainties, the following recommendations are made.

1. More data are needed to improve the emission factors tyre wear. The influence of a particular road surface on the wear factor, especially, is largely unknown. It is assumed that very open asphalt concrete causes greater abrasion to tyres than the smoother surface of closed asphalt concrete roads. Research into the influence of road surfaces can also help in the selection of efficient mitigation measures.
2. Approximately 40% of car tyre wear is retained in porous asphalt, according to the current expert-based assessment. The durability of this significant retention of tyre wear particles in porous asphalt needs further investigation. In the current assessment, the emission from porous asphalt into the surrounding environment is assumed to be negligible, but there are no confirmatory data. The maintenance of the porous asphalt and the method and frequency of cleaning practices should also be taken into consideration.
3. The contribution of car tyre wear relative to other traffic-related emissions of polymeric particles, such as the emissions from the brake system and from the road surface and road paints and from thermoplastic road markers, needs further investigation. Knowing the contribution of different sources and their distribution pathways helps to estimate the environmental costs and benefits and to identify the most potent measures that can be taken. The effect of road wear on roads with rubber components in them, such as noise-reducing roads, though still in an exploratory phase, needs further investigation.
4. The distribution pathways to sewerage, soil and surface water are based on expert judgement. Additional research is necessary to improve the underpinning of these rough estimates. Also fate and spatial distribution of tyre and road wear particles (TRWP) requires further research. Especially the distribution and retention by sewage treatment plants is considered a vital

pathway, but the efficiency of the STP to remove TRWP is largely unknown.

5. More data are needed on the effect of wheel alignment, tyre pressure and driving behaviour on tyre wear, which can be used in awareness-raising campaigns.
6. The exposure of aquatic organisms to traffic-related microparticles in rivers and the marine environment is largely unknown. Specific monitoring is required to assess the actual exposure and effects of the particles on aquatic organisms.
7. The contribution of different routes of human exposure to microplastics from these sources needs further quantification. With respect to TRWP, research conducted in recent decades has been focused on human exposure through the inhalation of traffic dust in the air. The significance of the recently raised issue of human exposure through food consumption[52] lacks data to support it.

6 Measures and instruments to reduce microplastics emissions

In this chapter, generic international and national actions related to the reduction of (plastic) litter and waste management are described. Subsequently, we more specifically focus on potential *technical measures* and *policy instruments* to achieve a reduction of microplastic emissions from the use of abrasive detergents, paints and tyres. In this study a distinction is made between measures and instruments. Measures refer to technical or practical actions with a certain potential to reduce microplastic emissions, whereas instruments refer to the way these actions are achieved. Measures indicate *what* could be done (for example substitution of an ingredient), whereas instruments indicate *how* it could be realized (for example by laws, subsidies or awareness raising). Whether a measure can reach its full reduction potential, will depend on the effectiveness of the instruments that are employed.

Given the exploratory nature of this research, the potential measures need to be understood as areas of interest. We list 'only' a number of options now for each source. The reduction potential, effectiveness, feasibility and socio-economic consequences of these potential measures and instruments should be further explored. This report also does not provide a cost-benefit analysis or a comparative life-cycle analysis between measures with respect to other environmental criteria (such as energy consumption, CO_2-production, safety and noise).

6.1 International approach

Currently, the Marine Strategy Framework Directive 2008/56/EC is the only legally binding directive in Europe and in the Netherlands that addresses microplastics. The Marine Strategy Framework Directive 2008/56/EC (MSFD) and the related Commission decision 2010/447/ on criteria and methodological standards on good environmental status of marine waters [2] mentions micro-particles and, specifically, microplastics as one of the indicators for a good ecological status of the marine environment. According to the MSFD, member states must develop monitoring methods in order to follow trends in the amounts and occurrence of microplastics. Furthermore, research must be conducted on the sources of microplastics and on measures that can reduce the quantity of microplastics [3].

The Netherlands is actively involved in the OSPAR Regional Sea Convention to investigate sources, the harmonization of monitoring methods and to investigate opportunities to reduce the emission of microplastics into the environment.

OSPAR is a Regional Sea Convention for the protection and conservation of the North East Atlantic, including the North Sea. The OSPAR Regional Action Plan (RAP) for the prevention and management of Marine Litter in the North-East Atlantic was adopted by OSPAR Contracting Parties[2] in 2014. The Regional Action Plan is a regionally coordinated set of actions

[2] The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

to address marine litter from major sea-based and land-based sources as litter already present in the marine environment. It contains three types of actions:

1. Common OSPAR actions: actions requiring collective activity within the framework of the OSPAR Commission through, where applicable, OSPAR measures (i.e. Decisions or Recommendations) and/or other agreements such as guidelines and background documents.
2. Actions to raise with other international organizations and competent authorities.
3. Actions that Contracting Parties should consider in their national programmes of measures, including those under the Marine Strategy Framework Directive. The approach regarding these national actions is based around the core principle that the RAP allows Contracting Parties to identify which of the measures and actions listed they have already taken forward (for instance, as a result of existing or planned national or European legislation or other initiatives) and to consider which others are needed to further combat marine litter. It therefore provides guidance to Contracting Parties and a framework for regional cooperation.

A total of 55 Collective Actions have been included in the RAP Marine litter. This document addresses two of the Collective Actions that deal with microplastics; i.e. Actions 46 and 47:

46. Evaluate all products and processes that include primary microplastics and act, if appropriate, to reduce their impact on the marine environment.

47. Engage with all appropriate sectors (manufacturing, retail, etc.) to explore the possibility of a voluntary agreement to phase out the use of microplastics as a component in personal care and cosmetic products. Should a voluntary agreement prove to be insufficient, prepare a proposal for OSPAR to call on the EU to introduce appropriate measures to achieve a 100% phasing out of microplastics in personal care and cosmetic products.

Because there is one common market in Europe and microplastics are a cross-border issue, an international approach seems most effective. On 9 and 10 December 2015, the Ministry of Infrastructure and the Environment, in cooperation with OSPAR, organized an international meeting for stakeholders, policy makers, EPAs and academia to discuss potential measures to prevent microplastics from entering the marine environment.

Measures to reduce microplastic litter may comprise several levels of the waste management hierarchy. The hierarchy establishes preferred programme priorities based on sustainability.

The waste management hierarchy indicates an order of preference for action to reduce and manage waste. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste. To be sustainable, waste management cannot be solved only with technical end-of-pipe solutions — an integrated approach is necessary.

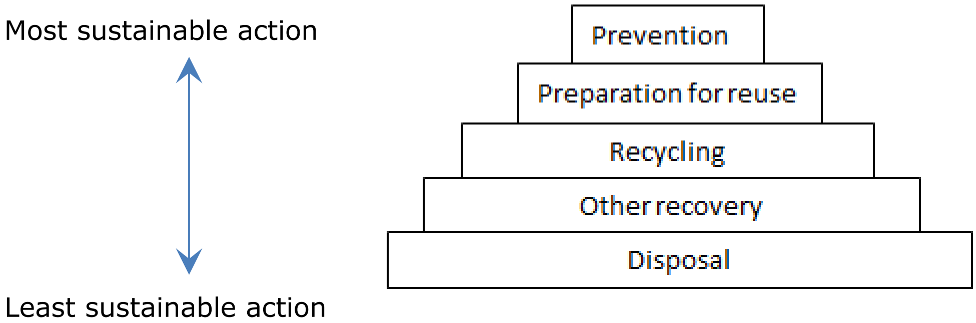

Figure 8 Generic waste hierarchy shows the most sustainable management option at the top and the least sustainable management option at the bottom of the waste management pyramid.

The hierarchy was first introduced in the Waste Framework Directive (75/442/EEC) and is now a component of all relevant waste directives. Its implementation is guided by the consideration of the Best Practicable Environmental Options, taking into account both social and economic costs. After end-of-life, plastic products may be recycled, used for energy recovery, put into landfills. Although landfilling (disposal) of plastics is the least preferred option, it is still the first option in many European countries. In the Netherlands, a landfill ban on plastics was implemented in 1996.

Leading principles included in the European Waste Framework Directive are the precautionary principle, the proximity principle[3], the polluter-pays principle and the producers' responsibility principle.

6.2 National approach

The Dutch government announced measures to reduce emissions of microplastics in its national programme of measures to improve the water quality in the marine environment [53]. The MSFD demands that each Member State submits such a national programme. The Water Framework Directive does not specifically mention microplastics. Environmental quality criteria are not available; not at the European level, nor at the national level. Moreover, microplastics are not included in regular monitoring programmes. Although microplastics are not explicitly addressed, an approach to reduce litter is described in the river basin management plans at the regional [54] and national levels [55]. Plastic litter is considered to be a significant source of microplastics [56].

The Dutch government formulated several additional measures for the MSFD that are aimed at:

1. Reducing litter arising from beach recreation, fisheries, ports and shipping: the Dutch government concluded “Green deals” with these sectors on concrete measures.
2. Encouraging awareness about plastic waste in the sea as a key component of prevention: through collaboration with

[3] The proximity principle advocates that wastes should be managed as close as is practicable to their point of origin. The principle is therefore aimed at ensuring efficient waste management practices, by minimizing the cost, resource use and emissions of transporting waste.

stakeholders along our main rivers, beach cleaning campaigns and school education.
3. Greater awareness concerning circular design, product development and the more sustainable and efficient use, recycling and reuse of materials. This is in line with the "green growth" and "circular economy" concept favoured by the Dutch government and, more recently, the European Commission as well.
4. The Dutch Plastic Cycle Value Chain Agreement, which was signed in 2013, and now supported by over 90 stakeholders from industry, science, NGOs and governmental agencies, is focused on promoting smart collaboration along the product value chains with the goal of accelerating concrete innovations in the market.
5. Cosmetic companies agreed to voluntarily replace plastic microbeads.

In this report, we further elaborate on potential measures to reduce microplastics released through the use of abrasive cleaning agents, paints and tyres. A distinction has been made between generic measures and product-specific measures.

6.3 Instruments

Environmental problems are usually addressed by employing a "policy mix" consisting of various command and control instruments, economic instruments and persuasive instruments. These instruments will be shortly described in this paragraph. In paragraphs 6.4 to 6.4.3, these instruments will be elaborated on for each source (abrasive cleaning agents, paints and tyres) and supplemented with some technical measures that could be viable.

6.3.1 Command and control instruments

Command and control instruments (CAC) can be defined as "the direct regulation of an industry or activity through legislation that states what is permitted and what is illegal" [57]. Environmental quality standards or setting emission levels are examples of a command and control instrument. The enforcement of these types of measures is a key issue that determines the effectiveness of the measures. The costs involved with enforcement may be high. A CAC approach is more feasible for point source than for diffuse, non-point sources. CAC regulation has the potential to lead to a more rapid resolution of certain environmental policy objectives. It may also provide clarity to those that are subject to the regulation. However, in international policy there is a tendency towards deregulation. The provisions in the MSFD mark the beginning of a command and control approach, with obligations for authorities to investigate the extent of the microplastic problem, the sources and the emission pathways.

Because a European definition of microplastics is not yet settled, an environmental quality standard is not feasible. However, in particular cases a ban on certain ingredients or the obligation for industries to use the best available techniques and best environmental practices to minimize microplastic emissions could be considered. A clear and binding definition could facilitate the implementation of measures, because it provides legal certainty and it enables the evaluation of compliance with environmental targets and the monitoring of the effectiveness of measures.

6.3.2 *Economic instruments*

Economic instruments for environmental protection are policy approaches that encourage things such as more environmental friendly behaviour through their impact on market signals, rather than through explicit directives focused on pollution control levels or methods or resource use [58]. Examples of economic instruments are: emission charges/fees/taxes; user charges/fees/taxes; product charges; tradable permit systems; non-compliance fees; deposit-refund systems; non-compliance bonds; performance bonds; liability payments; and subsidies. The yields of economic measures could be used to finance generic purification facilities or clean-up activities. Principle 16 of the Rio Earth Summit Declaration (1992) states that "National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should bear the cost of pollution with due regard to public interest and without distorting international trade and investment."

While voluntary approaches cannot compete with environmentally related taxes or emission trading systems in terms of economic efficiency, they can do better than traditional "command-and-control" regulations, because they can provide increased flexibility in terms of how a given target is to be met [59]. The effectiveness of voluntary approaches is questionable and often requires the alertness of a non-governmental organization (NGO) to keep the pressure on the subject. Free-riding – meaning that a company manages to obtain the benefits related to a given approach (for instance, to avoid the imposition of a tax or a stricter regulation), while not taking on any of the associated burden (for instance, abatement efforts beyond "Business-as-Usual") – is a significant problem with many collective voluntary approaches. A potential benefit of voluntary approaches – from an environmental point of view – is that they can require less preparation to put in place than regulatory approaches. Moreover, there are a considerable number of cases that indicate that companies can profit from taking such voluntary action. The Dutch Plastic Cycle Value Chain Agreement is an example of such a voluntary approach.

6.3.3 *Persuasive instruments*

Raising awareness is a powerful accelerator for voluntary measures and self-regulation, as was shown by the publicity generated by the Plastic Soup Foundation about microbeads in cosmetics. Awareness initiatives also can make alternative products or behaviour more fashionable and irresistible to consumers. Moreover, awareness can reinforce legal and economic instruments by creating an understanding of the need and benefits of such measures. Specific options are:

- accessible consumer information on products, sustainable behaviour and opportunities to improve;
- accessible information on stakeholders and their environmental performance;
- research, pilot and/or demonstration projects by stakeholders;
- government can act as an example via public procurement;
- public-awareness campaigns (through the media);

- awareness-raising for industries. A pilot campaign has started in Belgium, in which a tool is developed that enables companies to trace where, in their production process, primary microplastics are involved and how they can replace or reduce it [60]. The tool or assessment could be used within an environmental management system such as ISO 14 001;
- training and extension on best practice;
- children's education. Parents' awareness and understanding of environmental issues are frequently enhanced by their children's involvement in environmental education.

6.4 Potential measures

6.4.1 Abrasive cleaning agents

Substitution of microbeads in abrasive cleaning agents is considered as a technical measure to reduce microplastic emissions from this source. It could be implemented in several ways, each with different effectiveness prognosis.

Instruments that can be used to achieve substitution of microbeads in abrasive cleaning agents are:

1. a ban on microbeads;
2. a voluntary phase-out of microbeads;
3. awareness-raising.

1. A ban on microbeads
   This measure could be effective in phasing out primary microplastics in abrasive cleaning agents and other products that use primary microplastics. This measure is not relevant for secondary microplastics that are unintentionally generated during the use of paints and tyres. It is assumed that the measure is relatively cheap for industries because alternative ingredients are available. Many abrasive cleaning agents for household purposes already use inorganic ingredients such as silica, alumina or calcium carbonate. For certain niche products, such as cleaning agents for lenses and precision instruments, these alternatives may not be feasible. Industries will face costs to obtain a product registration for new product formulations. Additionally, the authorities will face costs for implementation and law enforcement. If the measure is implemented, it will create a level playing field on a European scale for all industries involved. The effectiveness of a ban is high; almost 100% reduction can be achieved. Because abrasive cleaning agents are a relatively small source, the overall reduction of microplastics in the environment is less significant.

   Recently, a national ban on microplastics or microbeads in cosmetic rinse-off products was announced in the United States. The US Federal Food, Drug and Cosmetic Act (21 U.S.C. 331) was amended[4] by adding the following:
   "The manufacture or the introduction or delivery for introduction into interstate commerce of a rinse-off cosmetic that contains intentionally-added plastic microbeads."

[4] https://www.congress.gov/bill/114th-congress/house-bill/1321/text

2. A voluntary phase-out of microbeads
   A voluntary phase-out could be a quick way to reduce microplastics from products, as was demonstrated by the phase-out of microbeads by part of the cosmetics industry. The measure is less effective than a legal ban, because not all manufacturers and trade companies will join the voluntary action (free-riders). Pressure from NGOs (in the case of cosmetics, the Plastic Soup Foundation) or consumers is considered essential for a voluntary measure to be effective. If a voluntary measure is confirmed by a form of (voluntary) agreement, the monitoring costs and obligations could be transferred to industries. A disadvantage is that an enforcement of the measure is absent, and continuous pressure or monitoring is necessary to guarantee long-term effectiveness. The advantage of a voluntary action is that the implementation and enforcement costs for the authorities are low and companies can implement the phase-out at their own pace, which minimizes the costs.

3. Awareness-raising
   Transparency about ingredients in abrasive cleaning agents is a way to raise awareness on this issue. Currently, information about ingredients in detergents is only accessible through the Internet, which forms a barrier for many consumers. Moreover, from the ingredients list it is not clear which ingredients are microplastics. Information printed on the packaging only concerns the presence of surface active ingredients. The EU Ecolabel helps consumers to identify products and services that have a reduced environmental impact throughout their life cycle, from the extraction of raw material through to production, use and disposal. General provisions of the EU Eco-label are laid down in EC Regulation 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Ecolabel. Criteria which must be fulfilled in order to obtain an Ecolabel are described in product-specific regulations. For example, for rinse-off cosmetic products, microplastics are included on the list of substances that shall not be used[5].

The EU Ecolabel logo for detergents means that:

- the product has a reduced impact on the aquatic environment;
- it does not contain certain dangerous substances;
- it has a limited effect on the growth of algae in water;
- it is largely biodegradable;
- it uses less packaging;
- it contains information on how to wash ecologically and economically;
- it is guaranteed to perform at least as effectively as conventional products.

Microplastics are currently not on the list of "Excluded or limited substances and mixtures" for detergents and other cleaning agents[5]. However, the criteria are currently under revision and stakeholders have suggested the possibility of ruling out the use of microplastics, regardless of their function, at the 2nd Ad-Hoc Working Group (AHWG)

[5] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0893&from=EN

meeting for the revision of the EU Ecolabel criteria for Detergent product groups held in October 2015[6].

6.4.2 *Paints*

A number of working instructions and regulations to reduce emissions from paint application have already been implemented in the Netherlands. They include, amongst other things, an obligation to cover work during abrasion and to have hard surface floors to facilitate cleaning (see Appendix 2). Other measures require a change in behaviour of DIY and/or professionals.

Five types of potential measures are identified:

1. paint innovation;
2. reducing the wear of coatings;
3. using methods that limit the spreading of dust during the removal of coatings;
4. reducing the amount of paint used;
5. preventing the rinsing of brushes and rollers in the sink.

Technical options related to the realization of these measures are described below. Legal, voluntary, economic or persuasive instruments can be employed to implement these technical measures (see paragraph 6.3).

1. Paint innovation

Paint innovation is considered a long-term measure. Paint innovation is a continuous, ongoing activity of industries. With respect to the aim of reducing microplastic emissions through paint wear, potential innovation could be directed to:

a. improving the wear resistance of the paint;
b. replacing persistent synthetic polymers with more environment friendly ingredients;
c. developing products (catalysts) that enhance the degradation of paint at end-of-life.

2. Reducing wear in coatings

Wear reduction will lead to larger maintenance intervals and thus to less wear and less spreading of paint dust. This may be done by:

a. improving the wear resistance of the paint itself (paint innovation);
b. improving the method of paint application, especially for DIY. Pre-treatment of the surface that needs to be painted (sanding and priming) can prevent untimely wear;
c. improving the lifespan of the paint by cleaning;
d. timely maintenance of the paint (before the layer starts peeling).

The first measure is already a continuous process for paint manufacturers, but wear resistance also depends on the quality of the construction, the quality of the paint application and circumstances during application and life-time (weather

[6] http://susproc.jrc.ec.europa.eu/detergents/docs/2ndAHWG_Detergents_Draft_Minutes.pdf

conditions, air pollution). For measures b-d, consumers and professional painters need to be informed.

3. Apply methods that limit the spreading of dust during the removal of coatings.

Dust capture and extraction can be done in several ways, such as by:

a. using mechanical collection of the paint dust while mechanically sanding;
b. good maintenance and adjustment of dust collection systems;
c. improving waste collection systems on the sanding machines and thus capture more particles;
d. performing the sanding activities indoors (unless this is not possible);
e. using fine nets to prevent paint from blowing away during outdoor maintenance activities;
f. collecting paint particles which have fallen on the ground (use a floor that can be cleaned very well);
g. selecting the best abrasion technique possible for each type of work (with the least emissions);
h. collecting and purifying wastewater from docks and slipways (in shipyards).

Some of the measures (d-f) are already required for the professional paint application sector.

4. Reduce the amount of paint used

It is recognized that a certain minimum amount of paint is required for the optimum protection of surfaces. However, application of too much paint or unnecessary painting should be avoided. Some options to reduce the amount of paint are:

a. The application of paint in a way that optimizes the amount of paint used. Special equipment exists for professionals that enables the application of just the right thickness of coating, which prevents redundant amounts of paint being applied.
b. The reduction of materials that need painting, i.e. less wood and more of other types of materials.
c. Also measures that reduce paint wear (1a-d) will lead to a reduction in paint use.

5. Prevention of rinsing of brushes and rollers in the sink

For emissions to the sewer resulting from the rinsing of rollers in the sink, there is no technical option available to prevent these emissions when rinsing the roller. Instruments to achieve this could focus on awareness-raising that the roller should be replaced instead of rinsed in the sink or by providing one free brush/roller for each bucket of paint in the DIY shop.

6.4.3 *Tyres*

For the purpose of this exploration, attention is given to potential measures that reduce emissions to the aquatic environment. Rubber particles are released from the tyre due to friction between the tyre and the road. This friction is needed for a good grip and good breaking properties.
The overall performance of tyres is a result of striking a balance between a large number of (often conflicting) quality aspects. Three of

those aspects form the basis of the European tyre label: rolling resistance (fuel consumption), wet grip (safety) and external noise. Improvement of abrasion resistance may result in reduced performance on one or more of the other aspects. Furthermore, it is essential to keep in mind that existing (safety) standards are being met. Since tyre wear depends on tyre composition, type of road surfaces, slope (mountains), climate and driving behaviour, an integrated approach is required to optimize the performance and minimize the wear of tyres. Further research into the effectiveness, potential negative side-effects and the feasibility of implementation of measures is needed to bring more focus to this list of options.

Potential measures to reduce car tyre wear are related to three different issues:
- emissions from tyres;
- effect of roads on the emissions;
- vehicle use and maintenance.

1. Improvement of the composition and structure of the tyres

Preventing or minimizing tyre wear in the first place will contribute to lowering the total amount of emissions. Car tyre manufacturing concerns an international market. The Netherlands only has one car tyre manufacturer. Because product requirements are laid down at the European level, innovations should be implemented at a European level. Two general options are identified:

a. Production of more wear-resistant tyres through changed composition and construction methods, e.g. see OECD [61]. Tyres with silica used as filler are, for example, less susceptible to wear than tyres with black carbon.

b. Production of tyres that are more resistant to degradation (aging) from UV, moisture and oxygen.

2. Improvement of the composition, infrastructure and maintenance of road surfaces

The road is the main area where tyre-wear particles are created and accumulated before they are dispersed into the surrounding environment. Minimizing tyre wear and the spread of tyre-wear particles helps towards controlling and lowering dispersion. Four general options have been identified:

a. Development of road surfaces that minimize abrasion: There are several main road types, each having unique characteristics with respect to tyre wear [62]. In general, roads with a coarser surface lead to more tyre wear. An example of a more recent innovation in this sector is ModieSlab, consisting of two concrete road plates atop a structural concrete layer. Laboratory experiments show a reduction of at least 50% in tyre wear compared with the commonly used porous asphalt roads [63]. Replacing current roads is expensive and will be a long-term process, considering it took around 35 years to reach 95% coverage of porous asphalt roads in the Netherlands. Nowadays, innovations are also aimed at energy reduction or even energy generation [64]. The cost-efficiency of road surface measures will be more positive when more environmental benefits are obtained than only tyre-wear reduction;

b. Construction of road surfaces that hold or filter tyre-wear particles;
   Although the Dutch porous asphalt is likely to increase tyre wear because the road surface has a coarser structure, it is at the same time a way to prevent emissions into the surrounding soil and surface water. Porous asphalt is less suitable for Nordic and alpine areas because frost damages the road surface. The prevention of rubber emission by porous asphalt is achieved as follows: porous asphalt contains pores that allow water to be quickly removed from the road surface, thus improving the safety conditions on the road. A side-effect of this is that, together with water, wear particles are also captured in the lower part of the porous asphalt layer. Whereas the water horizontally flows through to the verge and/or the soil, the particles are kept largely in the porous asphalt layer. Due to pumping action of the tyres at high speed, the rubber particles are transferred from the driving lanes to the emergency lanes;
c. Optimizing the cleaning of porous asphalt roads;
   In order to prevent clogging of the pores in the emergency lanes, the emergency lanes in the Netherlands are cleaned with high pressure vacuum cleaners approximately 1-2 times per year. Several types of cleaning equipment are available with different cleaning effectiveness. In a pilot study, approximately 15-28 kg was removed over a one-lane road length of 80 m of dirt, which doubled the permeability of the road surface for water and also improved the noise reduction properties [65, 66];
d. Timely road maintenance to minimize abrasion;
e. Adjustment of road infrastructure to be able to collect run-off water, for example, by installing gutters connected to the sewerage system along roads and highways;

Optimization of roads should be viewed in conjunction with the optimization of tyres. Therefore a joint approach between tyre manufacturers and road engineers is recommended.

3. Optimizing vehicle use and maintenance”

Several potential technical measures are identified that can reduce the wear of tyres:

a. maintaining the right tyre pressure. See, for example, www.bandopspanning.nl. As of 1 November 2012, all new-type vehicles will be required by EU law to have a pressure-based tyre pressure monitoring system installed;
b. correct wheel alignment and balancing;
c. timely change and correct storage of summer and winter tyres;
d. reduction of vehicle kilometres;
e. speed reduction.

Several persuasive, financial are control instruments are available to implement these measures.

6.4.4 Improvements of the sewerage system

The sewers transport run-off and wastewater containing microplastic particles and other waste materials from a variety of sources. Sewage treatment plants can be considered as last line of defence, filtering out micro plastics at the end of the pipe. However, when microplastics come from a large variety of diffuse sources, adjustments in the sewerage system and sewage treatment plant can be an effective way to reduce microplastic emissions into surface water. Several potential measures have been identified:

a. Adjusting the road infrastructure to be able to collect run-off water, for example, by installing gutters connected to the sewerage system along roads and highways.
b. Optimizing the sewerage system to minimize overflow and the untreated discharge of sewage.
c. Developing treatment methods that increase microplastic removal.

Potential measures "a" and "b" also have benefits with respect to reducing emissions of other contaminants into wastewater and storm water.

The distribution and transport of water from pavements to surface water, sewerage system and soil are mainly based on expert judgement, because experimental data are limited. Moreover, the current performance of sewage treatment plants with respect to microplastic removal is highly uncertain. Investment in end-of-pipe measures should therefore be preceded by proper research in order to assess the expected effectiveness and cost-efficiency of the potential measures.

7 Overall discussion and recommendations

This report focuses on emissions and reducing emissions of microplastics, following the aim of the MSFD to protect marine and freshwater environments. Uncertainties still exist about the critical levels of microplastics for aquatic ecosystems and humans. Valid reasons for reducing microplastics are the precautionary principle and the ambition to close loops of materials in order to achieve a circular economy and improve resource efficiency.

In a previous report, we included five criteria for the prioritization of microplastic sources and emissions [1]:

- extent of the emission;
- opportunity of quick win measures ;
- availability of alternative ingredients or materials;
- risk perception in society;
- action perspective of consumers.

Abrasive cleaning agents, paints and tyres scored relatively high using these criteria, although plastic litter, the handling of plastic pellets, laundry fibres and cosmetics also scored high. Laundry fibres and cosmetics were not included in our study because their emissions and potential measures are addressed within other activities. For plastic litter and pellets, measures have already been initiated. The aim of the current study was to estimate the extent of microplastic emissions from abrasive cleaning agents, paints and tyres and to obtain an initial idea of potential measures to reduce these emissions into surface water. The assessment is valid for the situation in the Netherlands.

The emission of microplastics from the three sources into surface water are given in Table 21. Although there are uncertainties and variability in the estimates, car tyre wear is undoubtedly the largest source, with a total emission of almost 1,800 tons per year. Compared with paints and tyres, the emissions caused by abrasive cleaning agents are relatively small.

Table 21 Overview of microplastic emissions (tons/year) from abrasive cleaning agents, paints and tyres into surface water in the Netherlands.

	To surface water	Uncertainty range
Detergents	1.2	0.2-2.2
Paints - construction - removal	52	
Paints - construction - rinsing	7	30-430
Paints - construction - wear	67	
Paints - shipping - wear	93	
Paints - shipyards	18	81-510
Paints - marinas	89	
Tyres	1,800	1,100-2,400

Uncertainties in Table 21 are related to emission factors and several environmental fate aspects of microplastic particles, such as the removal rate in sewage treatment plants. Especially when end-of-pipe measures are considered, more research is needed to assess the effectiveness and cost-efficiency of these measures.

When it comes to taking measures, a focus on reducing car tyre wear is evident, because a percentage reduction there would reduce the microplastic load being released to surface water substantially. However, measures can also be justified based on other reasons. For instance, a relatively small source like abrasive detergents scored high on the opportunity for a quick win measure. The report provides a preliminary list of potential measures than can be considered. We recommend further socio-economic analysis to assess the effectiveness, viability and cost and benefits of additional measures, for example:

Effectiveness

- Is the measure effective, i.e. how much reduction of microplastics is expected?
- Can it be implemented in the short or the long term?
- Will the measure have other positive or negative environmental impacts?
- Does the measure have a preventive or curative nature?
- Does the measure improve resource efficiency?

Costs and benefits

- What are the costs and benefits of the measure for industries?
- Does the measure stimulate innovation?
- Is it a sustainable measure?
- What are the costs and benefits of the measure for society/consumers?
- What are the cost and benefits in terms of added value and jobs?

Viability

- Is the technique available and is their proof of its applicability and effectiveness?
- Is the measure practically feasible?

The potential measures identified in this report need to be further elaborated with respect to the above-mentioned criteria.

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Appendix 1 Abrasive ingredients in cleaning products

Overview of abrasive ingredients in >400 cleaning products for hard surfaces from the major brands on the Dutch consumer market. Polymers are printed in bold.

Manufacturer/brand/product	Abrasive/polishing component
SCJohnson	
Mr. Muscle (25 products for cleaning hard surfaces)	
Mr Muscle Staalfix	Alumina
Mr Muscle Cerafixr	Alumina
Mr Muscle Ovenreiniger	None
Pledge (8 products for wood)	
Pledge Extra Protection wax and Pledge Extra Protection wax for wooden floors	**Butyl acrylate - methacrylic acid - styrene copolymer**[1] **Oxidized polyethylene**[1]
Bama (8 products for leather)	None
Kiwi (1 products for leather)	None
HG *(>300 products for cleaning and polishing)*	
HG Laminaat kracht reiniger	**Aqueous dispersion of styrene copolymer**
HG vinyl, linoleum & marmoleum vloeibare glanszeep HG vloertegel 'glans' reiniger (vloerfris) HG laminaat glansreiniger HG parket glansreiniger	**Acqueous zinc-containing styrene acrylic polymer dispersion**
HG vinyl, linoleum & marmoleum krachtreiniger	**Aqueous dispersion of styrene copolymer**
HG keramische kookplaat intensief reiniger	Aluminium, Quartz, Silicate
HG (Combi) magnetron reiniger HG keramische kookplaat alledag reiniger	none
HG Staalpolish	Aluminium, Aluminium-magnesium silicate
HG metaalglans	Aluminium, Aluminium-magnesium silicate, Quartz
HG vloerlijm verwijderaar extra sterk	**Hydroxypropyl methyl cellulose**
Reckitt Benkizer	
Brasso (3 products for delicate surfaces)	
Brasso Metal polish liquid	Kaolin (clay)
Brasso Metal polish wadding	Quartz
Brasso gadget care	None
Calgon (3 products for dishwashing)	

Manufacturer/brand/product	Abrasive/polishing component
Calgon tablets	granulated amorphous cellulose
Calgon powder	Zeolite, Natural Calcium / Sodium Benthonite
Calgon gel	None
Cillit Bang (37 products concern kitchen and toilet cleaners, dishwasher tablets, stain removers)	None
Dettol (65 products (including hand soaps, laundry detergents, floor, kitchen and bathroom cleaners)	None
Finish (25 products mainly for dishwashing)	None
Harpic (33 products for descaling and toilet cleaning)	
Harpic Max White & Shine Bleach – Lime Force	Silica
Harpic Max (4 aroma’s)	Silica
Harpic Cistern Block (3 aroma’s)	Hydrated silica
Mr Sheen (19 products for wood, floors and leather)	
Mr Sheen, Dilutable floor cleaner	**Polyethylene**[1]
Napisan stain remover	none
Scaleaway (2 products)	none
Silvo (2 products)	
Silvo Tarnish guard - Liquid	Quartz/kaolinite
Silvo Tarnish guard - Wadding	Quartz
Vanish(22 products for carpets and fabrics)	none
Vitroclen (1 product)	
Vitroceramic and stainless steel cleaner	Alumina
Windolene (3 products for window cleaning)	
Windolene cream	kaolin
Unilever	
Cif (39 products for hard surfaces)	
Cif cream lemon and 3 other fragrances	Calcium carbonate
Glorix : toilet cleaners	None
Colgate (9 Ajax products)	
Ajax bleach	*Calcium carbonate*
Other Ajax products (including dishwasher products)	None
Proctor and Gamble	
Mr. Proper (for bathroom cleaning)	No information available

[1]It is not clear if these ingredients are used as abrasive or as a wax.

Appendix 2 Some Dutch regulations that focus on preventing emissions into surface water (in Dutch)

Voor de bouw en voor scheepswerven in NL geldt:
Per 1 juli 2011 worden werkzaamheden aan vaste objecten (bijv gebouwen), zoals reiniging, conservering en onderhoud, geregeld met algemene regels volgens het Besluit lozen buiten inrichtingen (artikel 3.10 en 3.11) en het Activiteitenbesluit (artikel 3.6a en 3.6b).

De voorschriften voor het lozen van afvalwater dat vrijkomt bij het onderhouden, repareren en afspuiten van pleziervaartuigen zijn te vinden in de artikelen 4.75 en 4.87 van het Activiteitenbesluit (AB) en de artikelen 4.98 en 4.99 van de Activiteitenregeling (AR).

Scheepswerven zijn op grond van het Besluit omgevingsrecht (Bor) omgevingsvergunningplichtig. Het Activiteitenbesluit regelt geen specifieke activiteiten voor deze sector. Dit betekent dat het lozen van bedrijfsspecifieke afvalwaterstromen moet worden geregeld in de (water)vergunning.

Het Activiteitenbesluit bevat wel voorschriften voor het stralen van metalen (paragraaf 4.5.4). Deze zijn echter niet van toepassing op vergunningplichtige bedrijven. Inhoudelijk kan de vergunningverlener bij deze voorschriften aansluiten.

Organisatorische maatregelen gericht op het voorkomen van verontreiniging van het oppervlaktewater bij scheeps- en reparatiewerven zijn verwoord in de zogenaamde "Modelregeling Dok- en hellingvloerdiscipline".

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