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

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RIVM Report 2017-0193

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Colophon

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Synopsis

Potential measures against microplastic emissions to water

Microplastics are plastic particles that are smaller than 5 millimetres; through the use of plastic or rubber products these microplastics can end up in the environment (surface water, soil, and air). The uncertainty about the effect of microplastics for humans and ecosystems is still large. Therefore, precautionary measures are considered to reduce the emission of microplastics. RIVM has taken stock of the advantages and disadvantages of potential measures. This study focusses on three sources: abrasion of tyres (the biggest source) and paint, and microplastics added to abrasive cleaning agents (a minor source).

It is difficult to devise effective and feasible measures that significantly reduce such emissions. This is because abrasion cannot be completely prevented. A car tyre must have a short braking distance, and this is not possible without abrasion of the tyres. This example also illustrates how producers are confronted with many and often contradictory requirements in the area of effectiveness, safety, and environmental impact. In addition, influencing consumer behaviour is possible only to a limited degree. For example, abrasion of car tyres can be reduced by ensuring that the tyre pressure is maintained at the appropriate level. However, many drivers do not ensure that this is the case.

Preventive measures in particular would seem to be effective in reducing the emission of tyre wear particles. Such measures could include introduction of information provided to consumers about the susceptibility to abrasion of different types of tyres. Measures aimed at optimising tyre pressure, such as tyre pressure monitoring systems, can also significantly reduce emissions. Whether or not these measures are cost-effective will depend on how they are implemented. For example, they can be supported by legal regulations, encouraged via financial rewards, or brought to the attention of the public via an information campaign.

Keywords: microplastic, tyre abrasion, paint, abrasive cleaning agents, reduction potential, measures, feasibility, multicriteria.

Publiekssamenvatting

Potentiële maatregelen tegen microplastic emissies naar water

Microplastics zijn plastic deeltjes die kleiner zijn dan 5 millimeter; deze kunnen door het gebruik van producten van plastic of rubber in het milieu terechtkomen (oppervlaktewater, bodem en lucht). Er zijn nog veel onzekerheden over de effecten van microplastics voor mens en milieu. Daarom worden uit voorzorg maatregelen ontwikkeld die de uitstoot van microplastics kunnen verminderen. Het RIVM heeft de voor- en nadelen van mogelijke maatregelen op een rij gezet. Deze studie richt zich op bandenslijtage (een grote bron), verfdeeltjes en microplastics in schurende reinigingsmiddelen (een kleine bron).

Het is moeilijk om effectieve en haalbare maatregelen te bedenken die de uitstoot aanzienlijk verminderen. Dit komt onder andere omdat slijtage niet volledig te voorkomen is. Een autoband moet een korte remweg hebben, wat niet kan zonder dat de banden slijten. Dit voorbeeld illustreert ook hoe producenten worden geconfronteerd met, soms tegenstrijdige, eisen op het gebied van werkzaamheid, milieu en veiligheid. Verder is gedragsverandering bij consumenten maar in beperkte mate te beïnvloeden. Zo slijten autobanden minder als de bandenspanning goed is.

Vooral preventieve maatregelen lijken effectief om de uitstoot van slijtagedeeltjes te verminderen. Een voorbeeld is om de informatievoorziening over de slijtagegevoeligheid van verschillende soorten banden te verbeteren. Ook maatregelen die de bandenspanning optimaliseren, zoals controlesystemen, kunnen de uitstoot sterk verminderen. Of deze maatregelen kosteneffectief zijn, zal afhangen van de manier waarop deze worden geïmplementeerd. Ze kunnen bijvoorbeeld worden ondersteund door een wettelijke regeling, gestimuleerd worden door een financiële prikkel of onder de aandacht gebracht worden door een voorlichtingscampagne.

Kernwoorden: microplastic, bandenslijtage, verf, schurende reinigingsmiddelen, reductiepotentieel, maatregelen, haalbaarheid, multicriteria.

Contents

Summary

At the request of the Ministry of Infrastructure and Water Management, RIVM has prioritised potential measures for the reduction of microplastic emissions into water on the basis of a transparent assessment method. The Ministry aims to have detailed cost-effectiveness analyses (CEA) carried out for some of these measures. This report is intended to facilitate the selection of measures that will be subjected to such a CEA. The measures involve the following emission sources: tyre and paint abrasion, and microbeads in abrasive cleaning agents. On the basis of a earlier 'quick scan' by RIVM , these sources were selected by the Ministry of Infrastructure and Water Management after a discussion in Parliament(Ministerie van Infrastructuur en Milieu 2016).

Abrasion of tyres and paint contribute significantly to the emission of microplastic particles into the soil, water, and air. Within the OSPAR framework, it was estimated that, after plastic litter, tyre abrasion is one of the biggest sources of microplastic emissions to water, followed by paint abrasion. Abrasive cleaning agents contribute much less (<0.1%). Based on the precautionary principle and the ambition to realise a circular economy, organisations in Europe are involved in formulating measures to reduce the emission of microplastics. This ambition is also shared by the Netherlands.

RIVM has described 17 measures, 10 of which are intended to reduce tyre abrasion, 6 to reduce the dispersion of paint particles, and 1 to reduce microbeads in abrasive cleaning agents.

In this report, the reduction potential of the various measures is estimated, in other words the potential reduction in the quantity of microplastics released in tonnes per year. To do so, it was necessary to make assumptions about the effectiveness of various measures, because limited information was available. As a consequence, the estimated reduction potential is associated with a significant level of uncertainty, which can only be reduced via specific measurements. The estimated reduction potentials should therefore be interpreted as indicative values, that point out and rank opportunities for the reduction of microplastic emissions.

Measures aimed at reducing microplastic emissions caused by abrasion of tyres and paint are not simple. Most measures to prevent the formation of microplastic particles are difficult to realise, although not impossible, for several reasons. Firstly, the formation of such particles is inherent to the use of the products in question. Secondly, producers of such products are already having to deal with a large number of, often contradictory, requirements with regard to effectiveness and environmental and safety issues. Finally, consumer behaviour can be influenced only to a limited degree. Measures targeting tyre abrasion show the highest reduction potential. Preventive measures in particular are effective when it comes to reducing the emissions of abrasion particles, for example setting requirements with which tyres must comply in terms of susceptibility to abrasion, as well as providing

product information in that regard. Measures aimed at the optimisation of tyre pressure can also make a potentially significant contribution to emission reduction. Whether or not such measures are also cost-effective will depend upon how such measures are implemented, for example supported by legal regulations, with encouragement from financial incentives, or by focusing public attention on the topic at hand via an information campaign. Measures aimed at reducing the dispersion of paint particles have received less attention, although various approaches were raised that need further discussion and development in collaboration with stakeholders. A legal ban of microbeads in abrasive cleaning agents can only be taken within a European framework, but such measures contribute relatively little to reducing the overall emission of microplastics into water, because it is only a small source.

During workshops held with stakeholders, policymakers, and NGOs, it became clear that, in addition to the reduction potential, other issues such as practical feasibility and favourable or unfavourable side-effects for the environment and safety must also be taken into account. For example, what effects will the measures have on the reduction of energy consumption and the emission of greenhouse gases or on other aspects such as air quality, safety issues, and noise pollution? This information was added in a qualitative way (in the form of associated scores) in order to facilitate policy discussions related to the advantages and disadvantages of potential measures.

1 Introduction

1.1 Background

Plastic and microplastic (plastic particles smaller than 5 mm) (Verschoor 2015) in the environment are receiving a great deal of public attention. Campaigns such as 'Beat the microbead', which targets microplastic in cosmetic products, and 'The ocean cleanup' project by Boyan Slat have focused the attention of broad sections of the public on the issue. If present production and consumption trends continue, the quantity of plastic in the environment will continue to increase. The amount of plastic that ends up in the sea each year all over the world is estimated at between 4.8 and 12.7 million tonnes (Jambeck et al. 2015). There are presently both national and international ambitions and agreements that aim to reduce the emission of plastic and microplastic into the environment (EC 2013, EC 2015, EC 2017).

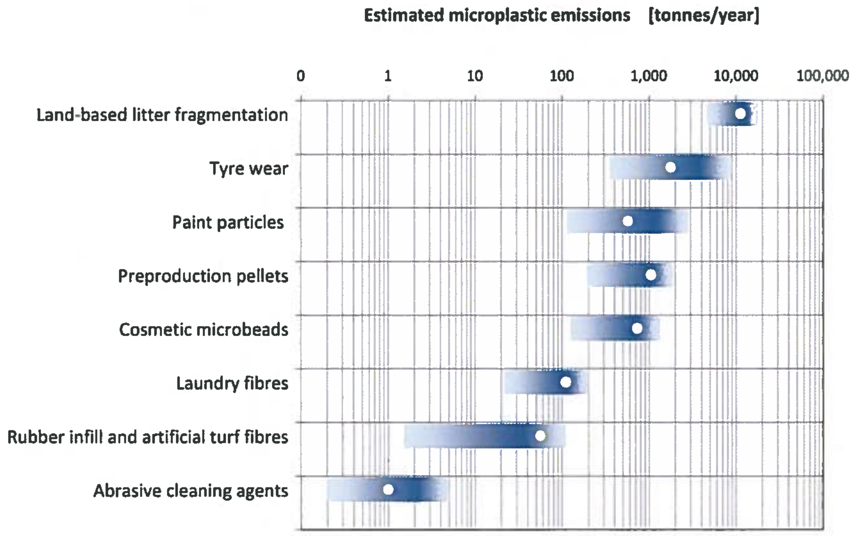

Figure 1 Estimated emissions of microplastics in Netherlands in tonnes/year. Derived from (OSPAR 2017). The columns show the uncertainty margins, and the white dot shows the average value.

Within the OSPAR framework, an inventory was made of a number of important sources of microplastics in the North-East Atlantic Ocean and the North Sea (OSPAR 2017). The conclusion was that, after plastic litter, tyre abrasion is one of the biggest sources of microplastic emissions to water, followed by paint abrasion. Abrasive cleaning agents are only a minor source (<0.1%). Microplastics are difficult to measure in the environment and are often difficult to trace back to the original sources. Therefore, the emissions are calculated based on production and product consumption data in combination with dispersion models. The estimates have a significant margin for error as a result of uncertainties and variations in product quality, consumer behaviour, geography, weather, infrastructure, and hydrology et cetera. Nevertheless, the emission estimates provide an overall view of the relative contributions from the various sources of microplastic emissions that can be used for prioritising sources and measures.

The presence of tyre particles in the environment is confirmed by measurements, but the number of studies focusing on their presence in the marine environment is limited (Wik et al. 2009, Norén 2011). Paint particles have been measured in freshwater as well as marine environments (Norén 2011, Takahashi et al. 2012, Song et al. 2015, Imhof et al. 2016). Microbeads that could have originated from abrasive cleaning agents have not been found in the marine environment.

The effect of plastic particles on organisms and humans is not clear, and assessment of the environmental and human health risks is a complex matter (Koelmans et al. 2017). Until now, effects have not been demonstrated for realistic concentrations in the environment. It is not known what effect the presence of increasing amounts of microplastics will have on humans and the environment in the long term. Based on the precautionary principle and the ambition to realise a circular economy, organisations in Europe are involved in formulating measures to reduce the emission of microplastics. This ambition is also shared by the Netherlands.

1.2 Goal

The goal of the report at hand is to select a number of measures for which, in a follow-up project, a cost-effectiveness analysis (CEA) has been carried out. The measures should lead to a reduction of microplastic emissions to water originating from tyres, paint, and abrasive cleaning agents. The report at hand was preceded by a process involving research and policy-making decisions as visualised in Figure 2.

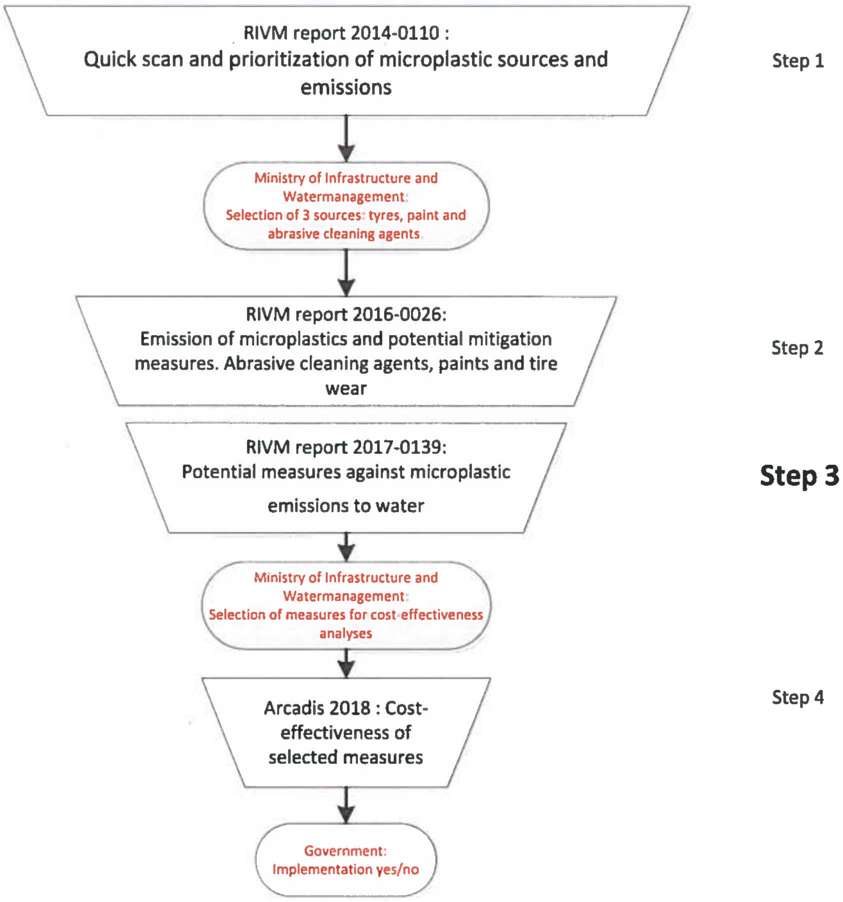

Figure 2 Process of research and policy-making leading to the selection of emission-reducing measures for microplastics. This report deals with step 3 in the above process

Step 1: Tyre wear particles (TWP), paint particles, and abrasive cleaning agents were selected after an analysis and prioritisation of microplastic emissions (Verschoor et al. 2014). The prioritisation was based, among other factors, on the extent of the microplastic emissions, the ability to influence consumer actions, the perception of risk, and the possibility of reducing emissions via relevant measures. Other sources that were assigned a high priority included waste materials and litter, clothing fibres, cosmetics, and microplastic pellets. These sources were not included in the present study, as they are already receiving attention from governments, researchers, stakeholders, and NGOs, for example in projects targeting litter at beaches (Green deal Schone Stranden), and in rivers (Aanpak Schone Maas), shipping waste (Green deal Scheepsafvalketen), fishing nets (project Vis Pluis Vrij), laundry fibers (Mermaids-project), ballons (www.dieballongaatnietop.nl) and microbeads in cosmetics (Beat the microbead Campaign).

Step 2: In 2016, RIVM carried out an in-depth study into the three selected sources of microplastics, namely tyres, paint, and abrasive cleaning agents (Verschoor et al. 2016). The goal of the study was to quantify the emissions and migration routes from these sources **in the**

Netherlands and to determine how these emissions can be reduced. The result was a long-list of approximately 40 possible solutions/approaches.

The above-mentioned RIVM report (Verschoor et al. 2016) served as the basis for further development of the proposed measures; a process in which representatives from the national government, civil society organisations, and sectoral organisations were consulted (see appendix 1). Within this context, the criteria were also discussed that should be considered of importance in comparing various measures. The involvement of stakeholders does not by definition mean that they completely support the content of this memorandum. After participating in consultations, RIVM made its own independent choice with regard to the assessment method used for the various measures.

This RIVM advisory report for the Ministry of Infrastructure and Water Management prioritises potential measures on the basis of their reduction potential. In addition to cost-effectiveness, policy choices made for the implementation of specific measures aimed at reducing microplastic emissions also depend on other factors. These include synergy with other environmental goals, the need for international collaboration, the length of time required to achieve results, and enforceability. This report also presents scores for these aspects, which can be taken into account by the Ministry in arriving at a decision.

Step 4: The cost-effectiveness of selected measures is a follow-up study by Arcadis; the results have been described in a separate report (Arcadis/SEO 2018).

2 Emissions and environmental impact in the absence of measures

The RIVM report on the emissions of microplastics from tyres, paint, and abrasive cleaning agents estimated that tyre abrasion is the largest of these three sources of emissions [13]. Most of these emissions end up in the soil, whereas a small part is emitted directly to the surface water. Part of the microplastic emissions that end up in the sewer system will eventually also end up in surface water. Based on the information available about the treatment yield of sewage treatment plants, overflow frequencies, and dry matter concentrations in sewage water and drains, we estimate that between 16% and 34% of the dry matter emissions discharged to the sewer system eventually end up in surface waters.[1] In Figure 3 we show the quantities that are discharged to the sewer system separately, as reducing the pollution load on the sewer system can be a criterion for assessing various measures.

Emission estimates are associated with uncertainties. The complex reality is simplified and represented by a mathematical model that estimates the formation and dispersion of particles. This model is based in part on measured input parameters and in part on assumptions. Existing mathematical models were used to estimate emissions insofar as possible, such as those developed by the National Pollutant Release and Transfer Register and the OECD Emission Scenario Documents. More information about the emission estimates can be found in the 2016 RIVM report [13]. The sections below briefly deal with the three separate sources.

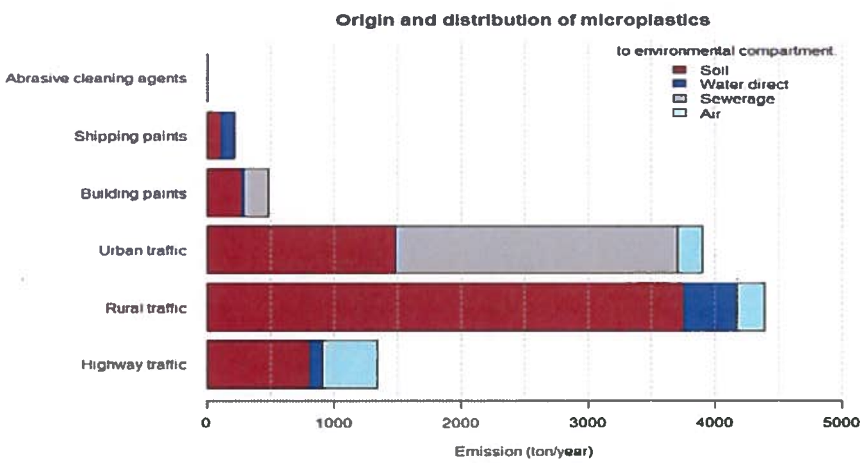

Figure 3 Origin and dispersion of microplastic emissions from tyres, paint, and abrasive cleaning agents (based on Verschoor et al. (2016)).

[1]60% of rainwater discharge in urban areas flows into the sewer system, 72% of which is diverted to sewage treatment plants, 8% to drains, and 20% to overflows. Treatment yield = 50% to 90%. Emission to surface water via sewer system = 72% x (1 - treatment yield) + 20% (see [8, Verschoor et al, 2016])

2.1 Tyre wear particles

The estimated total emission from tyre wear particles is 17,000 tonnes (Verschoor et al. 2016), of which approximately 10,000 tonnes ends up in the environment and 7000 tonnes ends up in porous asphalt (ZOAB). During the process of abrasion, part of the rubber becomes stuck to road surface particles. These heavy, combined abrasion particles, also referred to as Tyre and Roadwear Particles (TRWP), will therefore be deposited on the roadside surface or become incorporated into the porous asphalt. Another fraction of the particles produced consists of rather small free particles that can migrate into the environment via water. The origin of the particles and their dispersion in the environment is shown in Figure 4 and in Table 4 in Appendix 2. The graph shown on the left in Figure 4 makes it clear that most of the emissions originate from passenger cars (circa 60%). In addition, the largest quantity of tyre wear particles (circa 50%) is generated on motorways. This is because most kilometres are driven on motorways. However, a large part of the tyre wear particles generated on motorways are incorporated into porous asphalt. These particles are not free to migrate into the environment. Accordingly, the emission of particles into the environment from motorways is less than from country roads or from roads in urban areas (see graph on the right). The graph on the right in Figure 4 also makes it clear that most particles end up on or in the soil. In urban areas, a large part (circa 60%) ends up in the sewer system.

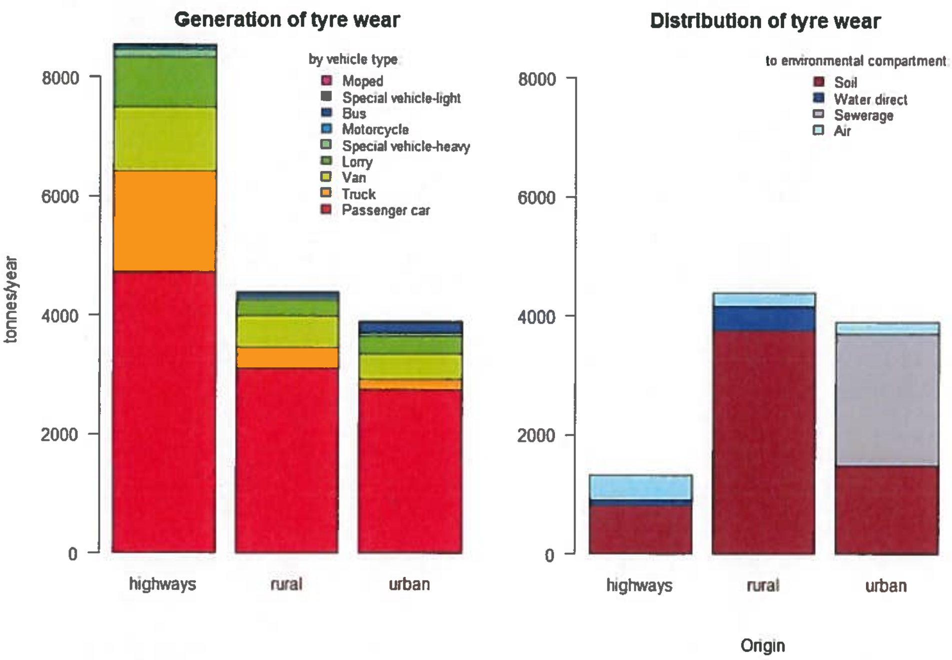

Figure 4 Formation and dispersion of tyre wear particles in the environment.[2]

[2] The emissions resulting from tyre abrasion and their dispersion into different environmental compartments was calculated in accordance with the method used by the National Emission Registration. This method is based on an emission factor that depends upon the vehicle and type of road in question and on the distances driven (traffic statistics) for 9 different types of vehicles on 3 different road types. The dispersion of the emissions into the environment is based on dispersion coefficients such as those used in the National Pollutant Release and Transfer Register (PRTR). The dispersion coefficients of the PRTR are based in part on research, such as studies into the performance of sewage systems, and in part on expert judgement and model calculations.

In urban areas, between 16% and 34% of the emissions end up in surface water via the sewer system (see footnote on page 15). This amounts to between 600 and 1300 tonnes per year. The dispersion of tyre wear particles into the environment is based on generic dispersion coefficients. In reality, the dispersion into different environmental compartments will be subject to significant variation, depending upon local circumstances such as the nearby presence of ditches, slopes, soil type and presence of vegetation, and the amount and intensity of rainfall. In spite of local or temporal deviations in the dispersion coefficients, this is the best estimate available of the dispersion into water, air, and soil on average at the national level in the long term. The dispersion of tyre wear particles also means that chemical compounds such as metals, polycyclic aromatic hydrocarbons (PACs), benzothiazoles, and aromatic amines end up in the environment. In 2007, for example, it was calculated that 40% of the zinc emissions into the soil and 27% of the sink emissions into water have their origin in traffic, in particular due to tyre abrasion (Mennen et al. 2010). Measures that reduce tyre abrasion provide an additional benefit by also reducing the emission of these compounds.

2.2 Paint particles

The total emission of microplastic paint particles is estimated at approximately 790 tonnes per year. Although the necessary measures have been taken at shipyards and marinas to reduce emissions, the remaining emission of such microplastic particles into water is estimated at 90 and 20 tonnes, respectively, per year. Depending upon the wind direction, approximately the same quantity ends up on the soil. In the building sector, the emissions end up primarily in the soil and the sewer system. Direct emissions into surface water are relatively minor. As is the case for tyre particles, between 16% and 34% of these emissions into the sewer system are estimated to end up in surface water (see footnote on page 15). The total emission into surface water resulting from paint used in the building sector is estimated at 10 to 30 tonnes per year in the do-it-yourself sector and 30 to 60 tonnes per year in the professional sector.

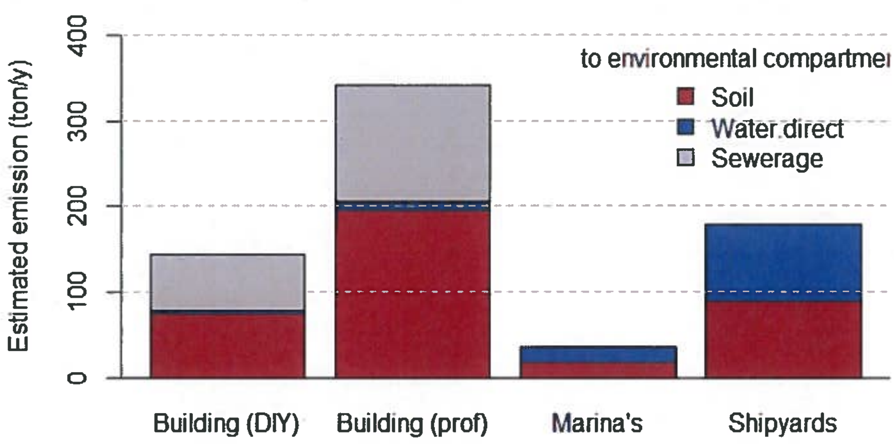

Figure 5 Origin and dispersion of microplastic emissions from paint.

2.3 Abrasive cleaning agents

The quantity of microplastics present in abrasive cleaning agents in the Netherlands is minor. The Dutch Association of Soap Manufacturers states that its members, who supply approximately 90% of the Dutch market, do not use any microplastics in their products. It's possible that microplastics are present in products that are supplied along with other products, for example with new kitchens, or products that can be ordered via web shops. The emissions via these channels is estimated at between 2 and 3 tonnes per year (also see (Verschoor et al. 2016)). These emissions are discharged almost entirely into the sewer system.

3 Potential measures

The long-list of solutions/approaches contained in the RIVM report 'Emission of microplastic and potential mitigation measures' (Verschoor et al. 2016) has been refined and aggregated to provide a list of 17 potential reduction measures. Only measures in which the government can play a role have been included. Measures that are already being utilised by branch-specific organisations or in which normal market forces can lead to emission reductions have not been included in this report.

Potential measures against emissions and dispersion of *tyre abrasion* (see Appendix 2):

- T1. Legal threshold value for tyre abrasion
- T2. Tyre label with tyre abrasion indicator
- T3. Reducing abrasion factor of road surface
- T4. Sustainability tool for road surfaces
- T5. Street cleaning campaigns in urban areas
- T6. Prohibiting the use of winter tyres in summer
- T7. Tyre Pressure Monitoring System in cars
- T8. Including wheel alignment in periodic vehicle inspections
- T9. Reducing maximum speed limits
- T10. Kilometre price

Potential measures against emissions and dispersion of *paint particles* (see Appendix 3):

- P1. Raising public awareness with regard to rinsing of brushes
- P2. Regulations for replacing older sanding machines
- P3. Covenant on residual emissions at shipyards
- P4. Subsidies for research into degradation of paint
- P5. Legally required guarantee period for paintwork
- P6. Reduction of residual emissions at marinas and storage facilities

Potential measure targeting microplastic in *abrasive cleaning agents* (see Appendix 4):
ACA European legislation prohibiting the use of microplastic in abrasive cleaning agents.

The measures are described in greater detail in Appendices 2, 3, and 4. There are 10 measures targeting tyre wear particles. These focus on the properties of the tyre, the road surface, the vehicle, the pressure of the tyre, wheel alignment, the use of summer tyres and winter tyres, driving behaviour, and vehicle characteristics. For paint, 6 measures have been worked out in more detail. These focus on paint innovation, durability of paintwork, the cleaning of brushes and rollers, equipment, and shipyards. One measure has been formulated in relation to abrasive cleaning agents, namely prohibiting their use in Europe.

A general point of departure in formulating environmental policy is the principle of proportionality. At the European level, the tendency is to implement additional regulations at the product level and to increase the responsibility of the producer. The concept of Extended Producer Responsibility (EPR) is set down in the European Waste Framework directive. Examples of EPR in the Netherlands include the requirement to pick up and recover plastic bottles and collection systems for products (waste disposal fee and disposal/collection facilities). The use of EPR as a measure in itself is not specifically described in this report, but some of the measures described in this report are of a technical nature and can serve as input for EPR.

In general, when formulating environmental policy, preference is given to preventive measures, i.e. source-based measures. If source-based measures are difficult to implement, then a measure implemented at the sewage treatment facility could be a cost-effective method to reduce some of the microplastic emissions into water. To avoid charging the public for these costs via taxation, a method would have to be found to charge the polluter for the extra costs.

During a stakeholders meeting on 13 September 2017 organised at the request of the European Commission, it became apparent that various numbers are in circulation regarding the percentage of microplastics removed from wastewater by wastewater treatment facilities in the EU (treatment yield). Eunomia Consultants carried out a literature study into treatment efficiency for microplastics and concluded that the removal rates vary between 53% and 84%. The sector itself (Eureau) claims that the yields vary between 80% and 99%. This includes unpublished data. The sector is making an effort to publish its own results.

In addition to the treatment technologies presently in use, there are also technologies available that are effective in removing microplastics in the nano-range. Eureau, the representative of the European companies active in the water and wastewater sector, refers to the following technologies in this regard: disc filtration, sand filtration, membrane microfiltration, and membrane bioreactors. These technologies are rarely used in Europe for the treatment of wastewater. The cost of setting up and using these methods is estimated at between €0.08 and €0.20 per cubic metre of water. An estimated 38 billion m^3 of water is treated each year in Europe.

The conclusion of the workshop was that the first priority is to ensure that the European guideline on the treatment of urban wastewater (91/271/EEG) is fully implemented. After that, the infrastructure can be improved (i.e. upgrading sewer systems and wastewater treatment facilities to include secondary treatment). Finally, additional measures could be implemented at the wastewater treatment facilities. In view of the fact that secondary wastewater treatment is utilised throughout the Netherlands and the preference for implementing measures closer to the source, this report will not deal any further with the improvement of supplemental treatment technologies.

4 Assessment framework

4.1 Assessment criteria

At the request of the Ministry of Infrastructure and Water Management, RIVM held discussions with stakeholders (Appendix 1) for the purpose of working out the measures from a previous RIVM report [4] in more detail and for making a list of the criteria considered important when it comes to comparing and setting priorities for potential measures. During these discussions, a great many aspects were mentioned that can be divided into four groups. These groups are explained further below.

- **Reduction potential:** The reduction potential is an indication of how much of a reduction of microplastic emissions (tonnes/year) can be achieved via a measure. The reduction potential depends on the technical nature of the measure and the target group at which the measure is aimed (for example a specific vehicle type, consumers, or the industry). As it turns out, the effectiveness of measures is difficult to describe in generic terms (Bemelmans-Videc et al. 2003). The degree to which the reduction potential is actually realised depends on a great many factors, including support level, price elasticity, and the manner and intensity of enforcement.
- **Environment & safety:** Are there any side effects associated with the measure? Can the measure have a synergetic effect on other policy goals or does it actually conflict with them? Attention points include energy savings and reduction of CO_2 emissions, reduction of other prioritised substances, contribution of the measure to circularity, and its influence on safety and/or health aspects for human beings, including the inhalation of particulate matter, noise pollution, and road safety.
- **Practical feasibility:** The following aspects play a role in this respect: 1) The playing field: Can the Netherlands introduce the measure autonomously at the national level or is a collective European approach needed? 2) The timeframe: How long will it take to implement the measure? 3) Compliance: The need and possibilities for enforcement. The criteria are explained further in Appendix 5. The technical feasibility is not included as a criterion but is viewed as a precondition. All the measures mentioned are considered to be technically feasible. The economic feasibility is dealt with under the aspect of cost effectiveness. The level of support is not taken into account here, as this can be influenced to a high degree. The goal of providing information to the public is to raise the level of awareness and support.
- **Cost-effectiveness:** This is an aspect that determines the economic feasibility of a measure. The cost effectiveness of a selection of potential measures chosen by the Ministry of Infrastructure and the Environment will be estimated in a follow-up study. The report at hand provides arguments on which this selection can be based.

4.2 Scoring and rating method

We used the *reduction potential* as the primary criterion for prioritising the measures. The aspects *practical feasibility* and side effects on *environment & safety* are secondary in this memorandum. However, these aspects are relevant for the final policy-based selection process, as is the cost effectiveness of a measure.

Reduction potential
The reduction potential is expressed as the reduction of microplastic emissions to water in tonnes per year. The reduction potential is based on statistics and technical information on paints and tyres. The reduction potential of the measures aimed at reducing tyre abrasion has been estimated for 9 vehicle types and 3 areas. With regard to paint, we differentiate between emissions from the maritime sector (marinas and shipyards) and the building sector (professional and do-it-yourself activities), as these are the sectors in which the most paint is used (Verschoor et al. 2016). The calculation of the reduction potential is explained per measure in Appendix 2 (tyre abrasion), Appendix 3 (paint particles), and Appendix 4 (abrasive cleaning agents).

Side-effects on environment & safety and practical feasibility
In order to get an idea of the side-effects for *environment & safety* and *practical feasibility,* it was decided to use a Multi-Criteria Analysis (MCA) (Huang et al. 2011). MCA is a research method that is used to make rational choices between options when several goals or criteria, each with a different character, are considered. In an MCA, these are associated with a value judgement in order to ensure that qualitative as well as quantitative aspects are added together to provide a total. One of the strengths of this method is that each step and decision in the evaluation process can be made transparent and explicit. This is important as prioritisation of the measures on the basis of an MCA requires one to make value judgements.

Appendix 5 indicates which options are available for scoring a measure for each criterion. An initial scoring round has already taken place on the basis of literature, talks with branch associations and policymakers, and information available on the Internet. This was followed by a feedback round, and the scores were adjusted if new information became available.

Final assessment
The process of arriving at a list of 'top 10' measures consisted of two steps:

1. Per emission source, the measure with the highest reduction potential was chosen. This satisfies the wish of policymakers to select at least one measure for each source.
2. Next, an additional 7 measures were chosen from the remaining group on the basis of reduction potential.

A total score for the MCA was calculated in order to quickly obtain insight into promising and less promising measures. A low MC total score can then result in further discussions regarding the weak points and the desirability of implementing such a measure. The total MCA score is a maximum of 10, whereby *environment & safety* and *practical feasibility* each contribute a maximum of 5 points.

4.3 Uncertainties in the effectiveness of measures

The uncertainty in the estimated reduction potential of the measures is rather large in all cases. This can be the result of uncertainties regarding the influence of the measure on the emission factor or of uncertainty with regard to the fraction of the emission (derived from the consumers, roads, vehicles, ships, buildings, and paint) targeted by the measure. Behavioural effects in particular are very difficult to estimate. For example, to what extent will people change their behaviour as a result of financial incentives (penalties, kilometre tax) or as a result of being better informed (information, TPMS). This will depend in part on the size of the penalty or reward and the nature and intensity of the information campaign.

A number of measures focus (in part) on enlarging the knowledge base and raising the level of information and awareness. Various overview studies clearly demonstrate the influence of information campaigns on behaviour. The direct changes in behaviour range from a few percent to over 15% (Snyder et al. 2004, Abroms et al. 2008, Anker et al. 2016). A meta-analysis by Snyder et al. (2004) of health-related campaigns shows that, on average, 8% of the target group exhibited the desired change in behaviour as the result of a campaign. However, there are large differences between different campaigns. The effectiveness of the various campaigns investigated (primarily in the area of health) correlates most strongly with the campaign topic. In addition, the effectiveness depends upon the goal of the campaign. For compliance or enforcement campaigns, effectiveness was an average of 17%; for non-enforcement campaigns, it was 5%, for prevention campaigns it was 3%, and 3% for campaigns focused on ending undesirable behaviour. The average effectiveness of the Postbus 51 campaigns of the Dutch government was 2% (Renes et al. 2011).

Behavioural aspects were taken into account in calculating the uncertainty margins. This report therefore presents a best-case scenario, whereby the focus is primarily on revealing the technical potential of the measures and assuming that all consumers and/or stakeholders comply with the measure. In addition, there is also a more realistic scenario in which, depending upon the type of measure, the effectiveness is lower because consumers and/or stakeholders do not implement the measure. The effectiveness of voluntary measures is less than that of mandatory measures. Behavioural effects can be influenced by external factors, depending upon the amount of time and money invested in creating a support base. The ease with which the consumer can actually comply with the measure also influences behaviour. When relevant, other aspects that have a significant impact on the reduction potential were also taken into account in the uncertainty margin.

In general, more information is available about tyre abrasion and the effect of measures targeting such abrasion than about paint particles. This is because a great deal of research has been carried out on the influence of various types of vehicles and roads on abrasion. Over the last decades, all kinds of measures have also been evaluated aimed at improving road safety and reducing traffic congestion, fine particles, and CO_2 emissions. These measures also often have an effect on tyre abrasion. In addition, the tyre industry and the VACO trade association have made information and statistics available on tire pressure, summer and winter tyres, and wheel alignment.

The topic of 'microplastics' is a fairly new one for the paint sector. There is therefore less data available that can serve as a basis for estimating the reduction potential in this area. It is therefore difficult to quantify the influence of paint quality, substrate quality, and paint application method on the emission of paint particles. In describing the measures, the aim was to provide an initial global estimate of the emissions and the effectiveness of relevant measures.

Uncertainties also apply to the assessment of *environment & safety* and *practical feasibility*. However, these are largely taken into account by using low-medium-high categories with scores of 1-2-3. There are possibilities for quantifying the criteria instead of assigning scores. However, this would require a significant research effort, which is not considered necessary for these secondary assessment criteria at this stage.

5 Results and discussion

In this report, the reduction potential of measures is estimated, in other words the potential reduction in the quantity of microplastics released in tonnes per year. To do so, it was necessary to make assumptions about the effectiveness of various measures because limited information was available. As a consequence, the estimated reduction potential is associated with a significant level of uncertainty. The reduction potential should be interpreted as an indication of where the biggest opportunities lie for the reduction of microplastic emissions. In order to reduce the uncertainties in the emission estimates and to check the effectiveness of the measures, we recommend carrying out system-focused measurements that contribute to a better understanding of dispersion models for specific sources such as tyre and paint abrasion.

An overview of the estimated reduction potential of the measures and the multi-criteria score of side effects for *environment & safety* and *practical feasibility* is shown in Table 1.

Table 1 Reduction potential and Multi Criteria (MC) score for the potential measures to reduce microplastic emissions.

No	Description	Reduction potential water (tonnes/y)	MC Score
	Tyres		
T1	Legal threshold value for tyre abrasion	200 (60-400)	5.9
T2	Tyre label with tyre abrasion indicator	200 (6-400)	5.3
T7	TPMS (Tyre Pressure Monitoring Systems) a. in all cars b. in old cars	 100 (5-300) 70 (5-100)	 9.1 9.1
T8	Wheel alignment as part of periodic vehicle inspections	50 (1-90)	9.7
T10	Kilometre price	10 (7-20)	7.7
T4	Sustainability tool for road surface	10 (<1-20)	7.2
T5	Street cleaning campaigns in the urban areas	10 (<1-20)	3.7
T9	Reducing maximum speed limits	9 (7-10)	8.2
T6	Banning the use of winter tyres in summer	9 (<1-20)	8.2
T3	Reducing abrasion factor of road surface	2 (<1-4)	6.1
	Paint particles		
P5	Covenant on residual emissions at shipyards	50 (9-90)	5.2
P1	Subsidies for research into degradation of paint	30 (1-60)	8.0
P4	Replacing older sanding machines	20 (2-30)	5.7
P6	Reduction of residual emissions of marinas and storage facilities	10 (2-20)	5.7
P3	Campaign aimed at raising public awareness with regard to rinsing of brushes	5 (<1-9)	6.0
P2	Legally required guarantee period for paintwork	4 (<1-8)	6.7
	Abrasive cleaning agents		
ACA	Banning products with microplastics	1	4.2

The measures are arranged per source going from the highest to the lowest reduction potential in water.

A total score for the MCA was calculated in order to quickly obtain insight into promising and less promising measures (see Appendix 6). In order to be able to evaluate the reduction potential and the MC scores for *environment & safety* and *practical feasibility* at the same time, they have been plotted against each other in figure 6. Each point corresponds to a measure.

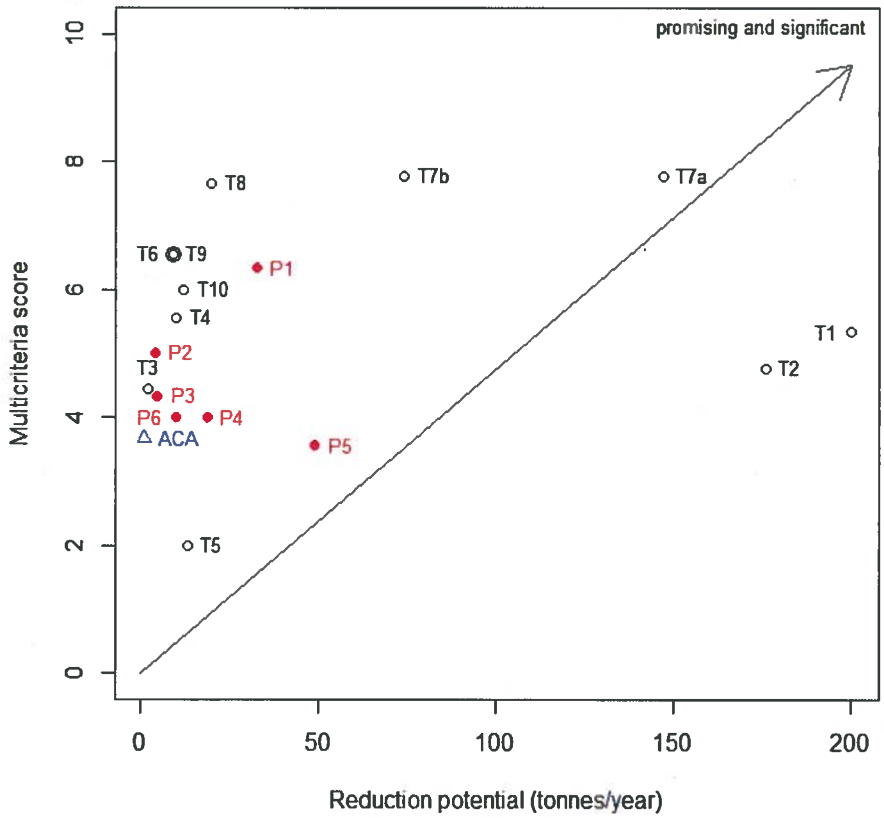

Figure 6: The estimated reduction potential of each measure for emissions to water (directly and via the sewer system) is plotted against the associated MC score. Uncertainty margins and codes are presented in Table 1.

The measures presented in the upper right corner of Figure 6 have the highest reduction potential and perform the best in the categories *environment & safety* and *practical feasibility*. In contrast, the measures shown in the lower left corner have the lowest reduction potential and perform the worst in the categories *environment & safety* and *practical feasibility*.

The measures with the highest reduction potential per product groups are:

- T1: Legal threshold value for tyre abrasion
- P5: Covenant on residual emissions at shipyards
- ACA: Banning products with microplastics

The measures with the highest reduction potential all target tyre abrasion. Measures that target the susceptibility to abrasion of the tyre (T1 and T2) and tyre pressure (T7a and b) have the highest reduction potential.

As tyres contain other chemical substances besides rubber, reduced abrasion also results in fewer emissions of chemical substances such as polycyclic aromatic hydrocarbons, heavy metals, and phthalates. The measures therefore also contribute to realising other water quality goals, as a result of which their cost-effectiveness increases. The same also applies to paint, which contains biocides, pigments, and solvents.

The measures with the highest reduction potential per source have a relatively low MC score. However, this does not mean that these measures are not feasible; with regard to certain aspects, they simply score less well than do other measures. These are aspects that can play a role in the political process. A low MC total score can then result in further discussions regarding the weak points and the desirability of implementing such a measure. The measures with the highest reduction potential for the three different sources (tyres, paint, and abrasive cleaning agents) are explained further below.

- The reason for the relatively low MC scores of measures T1 and T2, 'Legal threshold value for tyre abrasion' and 'Introduction of tyre abrasion indicator on the tyre label', is that they require international collaboration, which means that it will take quite some time to implement them. In addition, enforcement would be necessary but no consensus yet exists on how tyre abrasion can best be measured. The cost-effectiveness analysis must make it clear whether the reduction of microplastics achieved by the measure justifies the efforts that are required to implement the measure.
- The relatively low MC score for measure P5, 'Strengthening compliance with environmental guidelines at shipyards and marinas', is due to the fact that it does not yield any benefits in terms of energy and material consumption. In addition, it is not a preventive measure. The production of paint particles remains the same, but their dispersion is reduced. The measure scores well in terms of safety, as it results in less exposure by humans to particulate matter.
- The measure ACA, 'Ban on microbeads in abrasive cleaning agents', does not have a high reduction potential in absolute terms. The use of abrasive cleaning agents with plastic microbeads is minimal in the Netherlands, and the reduction of the emission to water is estimated at 1 tonne/year. The measure also scores poorly in terms of practical feasibility, as it would require international agreement and an enforcement system. This measure was nevertheless selected, as it is in line with a source-based approach and because a CEA (Cost-Effectiveness Analysis) can support the political decision-making process for implementing or not implementing this measure.

In order to make a good comparison of the cost-effectiveness of different measures, we recommend selecting several measures per source with as high a reduction potential as possible and as high a multi-criteria score as possible. This is not possible for abrasive cleaning agents, as only one measure is described for this source. The cost-effectiveness of this measure can be compared only to the cost effectiveness of measures that target other sources.

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Appendix 1 Organisations consulted

- Ministry of Infrastructure and Water Management
  - Directorate for Sustainability, Environment, and International policy
  - Directorate for Climate, Air, and Noise
  - Directorate for Safety and Risks
  - Directorate for Water and Soil
  - Directorate for Roads and Traffic safety
  - Human Environment and Transport Inspectorate
- Directorate-General for Public Works and Water Management [Rijkswaterstaat]
  - Water Traffic and Environment
  - Directorate for Sea and Delta
  - Department for Large Projects and Maintenance
- RecyBEM/NVR (Dutch Association of Rubber Manufacturers)
- Industry organisation for the tyre and wheel sector (VACO)
- Apollo Vredestein
- BOVAG
- ANWB
- Nederlandse Rubber en Kunststofindustrie (NRK) (Dutch Rubber and Plastics Industry)
- Plastic Europe
- Plastic Soup Foundation
- Nederlandse Vereniging van Zeepfabrikanten (NVZ) (Dutch Association of Soap Manufacturers)
- Vereniging Verf- en Drukinktfabrikanten (VVVF) (Association of Paint and Printing Ink Manufacturers)
- OnderhoudNL (Maintenance NL)
- Netherlands Maritime Technology (NMT)
- Unie van Waterschappen (UVW) (Association of Water Boards)
- STOWA (Foundation for Applied Water Research)
- Deltares
- TNO
- Royal Haskoning/DHV
- Arcadis

Appendix 2 Potential measures against emissions from tyre abrasion

Calculation method for reduction potential

This appendix describes potential measures that aim to reduce the emission or dispersion of tyre wear particles, namely:

- T1. Legal threshold value for tyre abrasion
- T2. Tyre label with tyre abrasion indicator
- T3. Reducing abrasion factor of road surface
- T4. Sustainability tool for road surfaces
- T5. Street cleaning campaigns in urban areas
- T6. Prohibiting the use of winter tyres in summer
- T7. a. TPMS in all cars
  b. TPMS in old cars
- T8. Including wheel alignment in periodic vehicle inspections
- T9. Reducing maximum speed limits
- T10. Kilometre price

The reduction potential is calculated as the difference between the emission if no measures are taken (see Table 2) and the emission after implementation of the measure (see formula 1). The emission of tyre wear particles is determined by the mileage, the abrasion factor, and the dispersion factor. Emission reduction measures can target one or more of these factors. The emission after implementation of the measure is calculated as follows:

Formula 1:

$$E_M = E_0 \times F.application \times F.reduction + E_0 \times (1 - F.tapplication)$$

in which:
E_M = emission (tonnes/year) after implementation of the measure
E_0 = emission before implementation of the measure *(*see Table 2*)*
$F.application$ = fraction of the total emission that falls under the measure
$F.reduction$ = relative reduction as a result of the measure

The formula simply expresses the fact that a part ($F.application$) of the total emission (E_0) falls within the scope of the measure and can therefore be reduced by a certain percentage ($F.reduction$)). The remaining part ($1 - F.application$) of the total emission (E_0) remains unchanged.
The calculation of the reduction potential of the measures is based on the following dispersion of emissions. See calculation method in Verschoor et al. (2016).

Table 2 Estimated emissions of tyre wear particles based on emission factors and mileages from the emission registration (Deltares et al. 2016) and scope of application of the measures T1 up to and including T10.

	Emissions (tonnes/year)				**Scope of application of the measures (X = yes)**									
	Soil	**Air**	**Water direct**	**To water via sewer system**[1]	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Urban areas														
Mopeds	8	1	0	3-7										
Motorbikes	9	1	0	4-7	X	X			X					
Passenger cars	1050	138	0	428-882	X	X			X	X	X	X		
Vans	159	21	0	65-134	X	X			X	X	X	X		
Tractors	118	15	0	48-99	X	X			X					
Lorries	66	9	0	27-55	X	X			X					
Buses	54	7	0	22-46	X	X			X					
Special vehicle (light)	1	0	0	0.6-1.2					X					
Special vehicle (heavy)	17	2	0	7-14					X					
Rural areas														
Mopeds	5	0	1	0				X						
Motorbikes	35	2	4	0	X	X		X						
Passenger cars	2655	155	295	0	X	X		X		X	X	X		
Vans	458	27	51	0	X	X		X		X	X	X		
Tractors	218	13	24	0	X	X		X						
Lorries	302	18	34	0	X	X		X						
Buses	44	3	5	0	X	X		X						
Special vehicle (light)	4	0	0	0				X						
Special vehicle (heavy)	32	2	4	0				X						
Motorways														
Mopeds	0	0	0	0										
Motorbikes	5	2	1	0	X	X	X	X					X	X
Passenger cars	449	236	54	0	X	X	X	X		X	X	X	X	X
Vans	101	53	12	0	X	X	X	X		X	X	X	X	X
Tractors	81	43	10	0	X	X	X	X						
Lorries	162	85	19	0	X	X	X	X						
Buses	2	1	0	0	X	X	X	X						
Special vehicle (light)	1	0	0	0			X	X						
Special vehicle (heavy)	12	6	1	0										

[1] A refinement and improvement of the arguments upon which the dispersion of dry matter via the sewer system is based was published in the emission registration in 2017 (Lieftink et al. 2017). These data were not taken into account here, but the estimated emission is expected to fall within the range mentioned here. The above refinement applies only to emissions to the sewer system in urban areas.

$F.application$ as well as $F.reduction$ consists of several factors. The relevant formulas are described below.

Formula 2:

$$F.application = F.target \times F.road \times F.vehicle \times Fbehaviour$$

in which:

$F.target$ = relative emission for the selected vehicles and road types (see crosses in Table 3) compared to the total emission (without the measure). F.target differs per measure and per environmental compartment (see Figure 7 and Table 3).

$F.road$ = fraction of the selected roads on which the measure can have an effect

$F.vehicle$ = fraction of the selected vehicles on which the measure can *have an effect*

$F.behaviour$ = fraction of or the degree to which the stakeholders will comply with the measure. This is actually the behavioural factor. As this factor is very variable and uncertain, we assume a best-case scenario for the prioritisation whereby F.stakeholder is 100%, unless specific information is available from comparable measures.

Formula 3:

$$F.reductie = F.abrasion \times F.dispersion$$

in which:

$F.abrasion$ = Relative abrasion after implementation of the measure (1 is no effect, <1 is reduction, >1 is increased abrasion)

$F.disperison$ = Relative dispersion of tyre wear particles after implementation of the measure

In Table 3 there is an overview of the input parameters for the calculation of the reduction potential. This appendix explains the arguments underlying these factors for each measure. The results of the reduction calculations are summarised in Table 4.

The reduction potential of measures T3 and T4 is time-dependent. The maximum reduction potential of T3 and T4 is realised only after 50 years (lifespan of DAB (non-porous asphalt) roads before replacement). To compare the reduction potential of all the measures we therefore use the average annual reduction over the first 10 years. This would seem to be a reasonable period of time for assessing the benefit derived from policy measures.

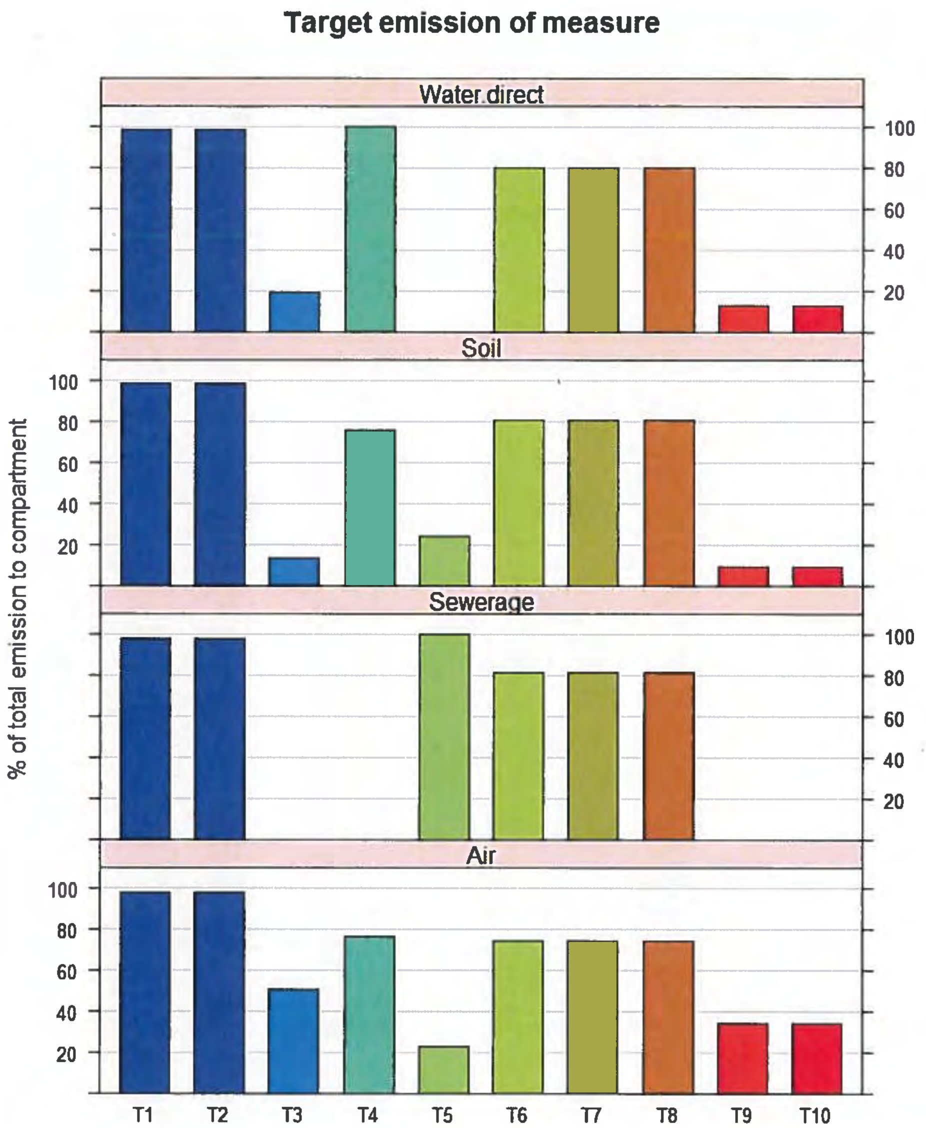

Figure 7 Fraction of the emission of tyre wear particles in the environmental compartment concerned to which the measure applies (F.target).

Table 3 Input parameters for estimating the reduction potential of the measures. Explanation in appendix T1 up to and including T10.

	Measure	F.target	F.road	F.vehicle	F.behaviour	F.abrasion	F.dispersion
T1	Legal threshold value for tyre abrasion	0.98	1	1	0.99-1	0.8-0.95	1
T2	Tyre label with tyre abrasion indicator	0.98	1	1	0.1-1	0.8-0.95	1
T3	Reducing abrasion factor of road surface	0.51	0.01-0.11	1	0.99-1	1.3	0.5
T4	Sustainability tool for road surface	0.77	0.01-0.11	1	0.1-1	1.3	0.5
T5	Street cleaning campaigns in urban areas	0.23	1	1	0.1-1	1	0.98-0,998
T6	Banning the use of winter tyres in summer	0.75	1	0.02-0.066	0.99-1	0.8-0.95	1
T7a	Direct TPMS in all cars	0.75	1	1	0.1-1	0.8-0.9	1
T7b	Direct TPMS in old cars (built before 2014)	0.75	1	0.5	0.1-1	0.8-0.9	1
T8	Wheel alignment as part of periodic vehicle inspections	0.75	1	0.22-0.44	0.1-1	0.85-0.95	1
T9	Reducing maximum speed limits	0.35	0.9	0.6	0.99-1	0.7-0.8	1
T10	Kilometre price	0.35	1	1	0.75-0.9	1	1

Table 4 Estimated reduction potential of measures to prevent (dispersion of) tyre wear particles [tonnes/year]. Average over the first 10 years after implementation of the measure.

Minimum	**total**	**soil**	**air**		**Water**	
				direct	effluent	total
T1	800	300	40	30	30	50
T2	80	30	4	3	3	6
T3	-30	3	2	0	0	0
T4	-4	2	0	0	0	0
T5	0	0	0	0	0	0
T6	1	0	0	0	0	0
T7a	100	50	6	4	5	9
T7b	60	20	3	2	2	5
T8	10	5	1	0	1	1
T9	600	60	30	7	0	7
T10	600	60	30	7	0	7
Maximum	**total**	**soil**	**air**		**water**	
				direct	effluent	total
T1	3000	1000	200	100	200	300
T2	3000	1000	200	100	200	300
T3	-300	30	20	4	0	4
T4	-400	200	20	20	0	20
T5	0	30	4	0	20	20
T6	200	60	8	5	10	20
T7a	3000	1000	100	80	200	300
T7b	1000	500	60	40	100	100
T8	800	300	40	30	70	90
T9	900	90	50	10	0	10
T10	1000	100	70	20	0	20
Average	**Total**	**Soil**	**Air**		**water**	
				direct	effluent	total
T1	2000	700	100	60	100	200
T2	2000	600	90	50	100	200
T3	-200	20	9	2	0	2
T4	-200	90	10	10	0	10
T5	0	10	2	0	10	10
T6	80	30	4	2	6	9
T7a	1000	500	70	40	100	100
T7b	700	300	30	20	50	70
T8	400	200	20	10	30	50
T9	800	70	40	9	0	9
T10	1000	100	50	10	0	10

T1 - Legal threshold value for tyre abrasion

Description: Introduction of a legal threshold value for tyre abrasion.

F.target	F.road	F.vehicle	F.behaviour	F.abrasion	F.dispersion
0.99	1	1	0.99-1	0.8-0.95	1

Minimising tyre abrasion has an immediate effect in reducing the quantity of microplastic emissions. However, modifying tyre characteristics in order to reduce abrasion can result in reduced tyre performance with regard to the present indicators of the tyre label such as fuel consumption (rolling resistance), safety (grip), and noise emission. It is assumed that the safety standards for tyres will be maintained. It is possible to introduce a legal threshold value for tyre abrasion whereby the tyres most susceptible to abrasion are phased out of production while maintaining acceptable characteristics for the tyre label. Experts from the tyre sector estimate that the wear characteristics of tyres with an EU label vary by 10% to 20% (personal communication). An American database containing over 4000 tyres states a variation of roughly the same size for the 'wear rating' (mileage) characteristic (NHTSA). There is no European or Dutch database available with tyre wear characteristics. We therefore use the American database, which may include tyres not available on the European market, only for verification of the estimate provided by European experts. It should be noted in this regard, however, that mileage characteristics are not always the same as wear characteristics. As a good alternative may not always be available for all types of tyres, we assume that the reduction may be less than the 10% mentioned earlier. We therefore assume a reduction in the range of 5%-20% (F.abrasion = 0.8-0.95). The measure is assumed to be applicable to all vehicles except the special light and heavy vehicles (F.target = 0.99). Within this selection, the measure is applicable to all roads (F.road = 1) and all vehicles (F.vehicle = 1).

The tyre label is international, and an enforcement system will be needed.

An international consensus must be reached in order to ensure that a harmonised and validated method for measuring abrasion can be developed and applied.

T2 - Tyre label

Description: Raising the level of awareness under consumers by supplementing the EU tyre label with an indicator for abrasion.

F.target	F.road	F.vehicle	F.behaviour (best-case)	F.abrasion	F.dispersion
0.99	1	1	0.1-1	0.8-0.95	1

This measure is less binding and more voluntary than the measure involving a legal threshold value (see T1). The maximum reduction potential of the measure is the same as T1, but the effectiveness of a tyre label that focuses on raising the level of awareness and knowledge can differ from that of a measure based on a legal threshold value. It is not possible a priori to predict whether the effectiveness of this measure can approach that of a legal threshold value, and we therefore assume a best-case scenario, whereby this measure is just as effective as a legal threshold value. The effectiveness of this measure in comparison to a legal threshold value will also depend on the threshold value chosen as well as how familiar consumers are with the tyre label and the consumer's willingness to pay extra for a tyre with a longer usable lifetime. A survey of 873 respondents showed that three-quarters of consumers are not familiar with the tyre label.[3] As opposed to a legal threshold value, the focus of this measure is on raising public awareness, consumer freedom of choice, and market forces. It's essential to increase public awareness of the tyre label for the measure to be effective.

T3 - Reducing abrasion factor of road surface

Description: Replacement of DAB (non-porous asphalt) top layers of motorways by ZOAB or 2L-ZOAB (types of porous asphalt).

F.target	F.road	F.vehicle	F.behaviour	F.abrasion	F.dispersion
0.51	0.01-0.11	1	0.99-1	1.3	0.5

Approximately 95% of the motorways are surfaced with porous asphalt (ZOAB) and 5% with non-porous asphalt (DAB). (Deltares et al. 2016) Studies have shown that tyre abrasion on ZOAB is 30% to 35% higher than on DAB (van Blokland et al. 2009), so that this measure would lead to increased abrasion (F.abrasion = 1.3). On the other hand, the tyre wear particles are largely absorbed and retained in the ZOAB layer so that the emission of particles from such roads to surface water is 20 times less than from DAB surfaces. (Deltares et al. 2016) More wear particles are washed away from DAB surfaces as DAB does not have any open pores that can retain the wear particles. Calculations have shown that at present 10% of the emissions can wash away (5% DAB x 1 + 95% ZOAB x 0.05). If all the motorways were surfaced with ZOAB, then the estimated emission of particles would be 5% of the total amount that can be produced. The dispersion would therefore be reduced by 50% compared to the situation without any measure being taken; F.dispersion = 0.5.

Due to the higher percentage of hollow space, ZOAB is less suitable for use in curves, exits, and crossings as it would tend to break down more quickly in such situations. ZOAB is often not an option on secondary roads and roads in urban areas as it wears down more quickly in curves and in places where cars brake and accelerate more frequently. The calculation of the reduction potential therefore applies only to motorways, where 51% of the total emissions originate (F.target = 0.51).

[3] http://nos.nl/artikel/2160343-zomerbanden-of-winterbanden-sommigen-hebben-geen-idee.html (article on 'summer tyres or winter tyres - some have no idea')

The point of departure here is that the replacement of DAB by ZOAB is carried out, insofar as possible, as part of the existing renovation and replacement scheme. DAB is assumed to have a usable lifetime of 40-50 years. Our point of departure is therefore that 2% of the present DAB is replaced per year. In fact, the total reduction potential will be realised only after all the DAB surfaces have been replaced, in other words after a maximum of 50 years. To compare the reduction potential of various measures, we use the average values over the first 10 years. The average replacement percentage over this period is 11%. The lower limit for the average replacement percentage of DAB surfaces was set at 1%, as not all DAB surfaces may be suitable for replacement by ZOAB (F.road = 0.01-0.11). The measure does not differentiate between vehicle types (F.vehicle = 1).

The replacement of ZOAB by two-layer ZOAB does not appear to be very effective in reducing the emission of tyre wear particles to soil and water and is therefore not part of this measure. Although two-layer ZOAB does reduce abrasion to a limited extent (approximately 4% less than regular ZOAB, (van Blokland et al. 2009)), the ability of both types to retain wear particles is the same. The degree to which (2L) ZOAB has an effect on emissions to the air has not been properly quantified. However, there are indications that the resuspension of particles on 2L-ZOAB is lower than on DAB (Hooghwerff et al. 2007). The resuspension also depends on the weather conditions and the presence of road salt.

Fuel consumption of motor vehicles is lowest on DAB road surfaces, followed by two-layer ZOAB surfaces, and is highest on ZOAB surfaces. Replacing ZOAB by two-layer ZOAB therefore has a positive effect on fuel consumption. The replacement of DAB road surfaces has a positive effect on noise pollution and on road safety, as it reduces the risk of aquaplaning.

T4 - Sustainability tool for road surface

Description: Information campaign aimed at encouraging the use of the sustainability tool by road construction companies.

F.target	F.road	F.vehicle	F.behaviour	F.abrasion	F.dispersion
0.77	0.01-0.11	1	0.1-1	1.3	0.5

Installing a road surface with a lower abrasion factor reduces tyre abrasion and therefore also reduces the emission of microplastics. The Directorate-General for Public Works and Water Management (Rijkswaterstaat) participates, under the flag of the European CEN standardisation committee, in the development of a sustainability tool named LCE4ROADS (www.lce4roads.eu). A workshop agreement is in place for a methodology that can be used to assess the sustainability of roads, which can be used by road authorities in the selection process that precedes the building of a road. This tool takes into account environmental, societal, economic, and technical aspects. The present version does not explicitly take into account the abrasion factor of the road surface for tyre abrasion. During further modifications of the tool, the Netherlands could propose integrating this aspect in the tool.

Another approach to a road sustainability tool is the development of a road surface label. A road surface label is being promoted by the Province of Gelderland, the University of Twente, a building company (Strukton Civiel), and the tyre industry (Apollo-Vredestein).[4] The focus of that road surface label is presently on fuel consumption, safety, and noise. An indicator of tyre abrasion should be included in order to reduce tyre abrasion.

Gomes Correia et al. (2016) have published an overview article on sustainability methodology for infrastructure works. This article also does not devote any attention to the abrasion factor.

We assume that the tool may possibly also be used for choosing the most appropriate road surface for secondary roads. Together with motorways, these roads are responsible for 77% of tyre wear particles (> F.target = 0.77) The other reduction factors are the same as for measure T3; see explanation for T3. However, as the measure depends more on raising public awareness than on enforcement, the reduction realised in practice will probably be lower.

T5 - Street cleaning campaigns in the urban areas

Description: A covenant with cleaning services in urban areas aimed at realising 4 extra sweeping rounds per year.

	F.target	F.road	F.vehicle	F.behaviour	F.abrasion	F.dispersion
T5	0.23	1	1	0.1-1	1	0.98-0.998

The measure applies to emissions in urban areas, which are responsible for 23% of the total emission (F.target = 0.23). This measure prevents the dispersion of tyre wear particles to the sewer system; it is not a preventive measure that reduces tyre abrasion. Street sweeping activities are carried out in order to prevent sewer drains from becoming blocked. In some municipalities, street sweeping is carried out at a fixed frequency. In other municipalities, the frequency depends upon preceding visual inspections. A limited survey carried out of 8 municipalities identified frequencies of 2 to 12 times per year.

Studies show that the efficiency of the sweeping vehicles in removing fine particles varies between 0% and 100% (Idae[a] 2013). This is because the method is most effective if roads are swept just before a rain shower, but it's difficult to coordinate such activities with the weather forecast. If no additional measures are taken, the total emission to water in the urban areas is estimated at approximately 1200 tonnes/year. Increasing the frequency of street sweeping rounds from an average of 4 times to an average of 8 times per year can (assuming an estimated efficiency of 0% to 100% per sweeping round) reduce the emission of tyre wear particles into water by 0 to 70 tonnes per year (average value for 50% efficiency: 10 tonnes/year). This estimate was arrived at by combining 4 extra fixed dates for sweeping with 145 randomly selected days of rain on which all the particulate matter on the

[4] http://www.strukton.nl/nieuws/2016/labelling-van-wegdekken-vooruitgang-verzekerd-/

streets is washed into the sewer system and the road verge. The random procedure was iterated 1000 times (1000 simulated years with different days of rain), resulting in a random distribution of the amount of microplastics that is removed each year (See Table 4).

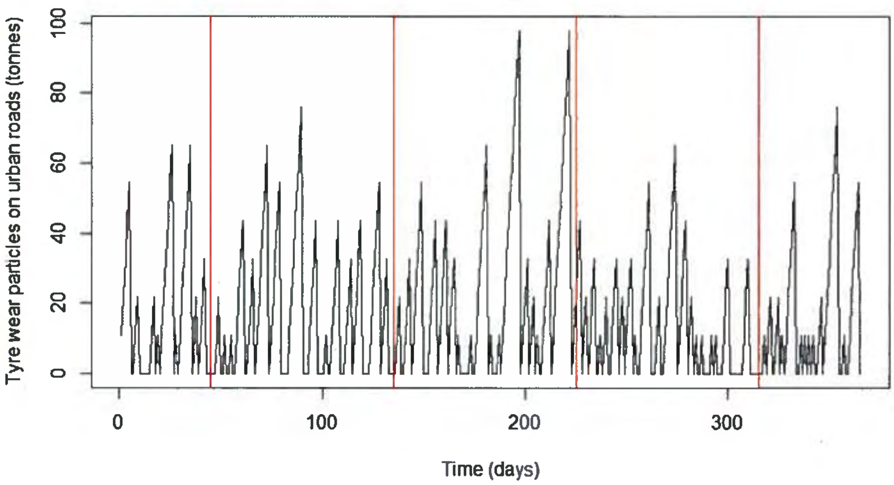

Figure 8 Simulation of the total amount of tyre wear particles on urban roads over a year with random intervals of rain. The red lines represent sweeping rounds. The peaks represent the amount of accumulated tyre wear particles on the road on 145 randomly chosen days of rain. The maximum rainfall per day is set at 10 mm.

Table 5 Estimate of the amount of tyre wear particles removed per year on the basis of different assumptions regarding the removal efficiency per sweeping round. Simulation of 1000 years with different rainfall patterns.

Hypothetical efficiency per sweeping round	Calculated mass of tyre wear particles removed [tonnes/year]		Calculated percentage tyre wear particles removed [tonnes/year]
	25th to 75th percentile	average	average
10%	3-8	6	0.2%
25%	7-23	16	0.4%
50%	15-41	31	0.8%
75%	23-61	47	1.3%
90%	27-73	55	1.5%
100%	30-81	63	1.7%

Sweeping leads to a reduction in the dispersion of tyre wear particles to soil, water, and air within the urban areas. The exact amount removed depends on the weather conditions and the time chosen for sweeping. These conditions are by their very nature quite variable, and the estimated removal is therefore by definition uncertain. The removal efficiency is also variable (Idae[a] 2013). The weather as well as the removal efficiency were therefore varied in order to calculate the uncertainty margins. In Table 5 the 25th to 75th percentile is shown; in other words, the reduction potential lies between the values shown in half of the simulated years. The removal was lower in one quarter of the years and higher in one quarter of the years.

Based on the calculations and simulations in Table 5 the value of F.dispersion was set at 0.98-0.998. Emissions to water and soil are reduced by this percentage.

Street sweeping activities also result in the removal of litter, weeds and leaf waste, and dog excrement. The aesthetic value and safety (health) of the surroundings increase as a result. An increased frequency of street sweeping rounds can contribute to a reduction in the costs of cleaning sewer drains.

T6 - Summer and winter tyres

Description: Introduction of a ban of the use of winter tyres in summer

	F.target	F.road	F.vehicle	F.behaviour (best-case)	F.abrasion	F.dispersion
T6	0.75	1	0.02-0.06	0.99-1	0.8-0.95	1

The measure applies to passenger cars and vans on all roads, which account for 75% of the total emission (F.target = 0.75). Winter tyres are recommended by the tyre industry because at low temperatures (< 7 degrees Celsius) and on snow they hold the road better than do summer tyres, in which case the braking distance of winter tyres is significantly shorter than that of summer tyres. The use of winter tyres in winter is required by law in some countries but not in the Netherlands. In summer, winter tyres are less safe, as the braking distance is longer. They are also more susceptible to abrasion.[5] A survey carried out by Kwikfit of 2200 cars concluded that 4.2% of the cars were fitted with winter tyres in the summer of 2016[6]. Due to variation and uncertainty in the random sample, we assume that this percentage varies over a range of 2% to 6% (F.vehicle = 0.02-0.06). Quantitative data was not available on the effect of using winter tyres in the summer on tire abrasion. Information was available on its effect on braking distance and fuel consumption. At 100 km/hour, the braking distance of a car with winter tyres in the summer was 17% longer than that of a car with summer tyres. The fuel consumption of a car with winter tyres in the summer was 15% higher[7]. We assume that similar percentages apply to abrasion. It is not known whether the test conditions are representative for Dutch summers or how large the variation is between different tyre brands. A range of values was therefore assumed for F.abrasion equal to 0.8-0.85 (corresponding to a reduction of 5% to 20%). The all-season tyre is a compromise between a summer and a winter tyre. Approximately 4.7% of cars were fitted with all-season tyres in the summer of 2016.[6]

[5] https://www.anwb.nl/auto/themas/winterbanden/met-winterbanden-de-zomer-door-kan-dat
[6] www.kwik-fit.nl/nieuws/bandenmonitor/kwikfit-bandenmonitor-najaar-2016-rubberen-voetafdruk-big-five-groeit-weer
[7] https://www.conti.nl/nieuws/winterbanden-niet-gebruiken-in-de-zomer/#

The tyre industry provides a fair amount of information with regard to the correct use of summer and winter tyres, especially during the times that tyres need to be changed, the so-called tyre change weeks. Advertisements on radio, messages on matrix boards and websites (www.kiesdebesteband.nl; www.debandenwisselweken.nl) are used to inform the public.

Changing summer and winter tyres is specialised work that can only be done in a garage, as the tyre must be removed from the wheel rim. Only car owners who have a double set of wheel rims can, if they so wish, change from summer to winter tyres and vice versa by replacing the entire wheel. The advantage of having the tyres changed in the garage is that the garage combines the tyre change with an inspection of the wheel (abrasion), the tyre pressure, and the wheel alignment/balance. These factors have a great influence on tyre abrasion.

The possibilities for optimising the use of winter tyres are limited by our unpredictable weather conditions. Our winter temperatures regularly dip below and then quickly rise again above the freezing point. Temperatures often exceed 7 degrees, which is unfavourable for winter tyres, but we also experience snow, glazed ice, and frost, which is unfavourable for summer tyres. If, besides the information already being made available to the public, an additional measure needs to be considered, then a ban on the use of winter tyres in the summer would seem to be the most logical choice. Such a measure could apply to motorcycles, passenger cars, and vans. Temperatures from April up to and including October are generally above 7°C. Such a ban has already been implemented in Italy[8].

Lorries and buses would be excluded from this measure. We assume that the use of summer and winter tyres for such vehicles has already been optimised for business reasons. However, no information is available to verify this assumption.

T7 - Tyre pressure

Description: Promoting a Tyre Pressure Monitoring System (TPMS) for passenger cars and vans.

	F.target	F.road	F.vehicle	F.behaviour (best-case)	F.abrasion	F.dispersion
T7a (all build years)	0.75	1	1	0.1-1	0.8-0.9	1
T7b (only cars with build years < 2014)	0.75	1	0.5	0.1-1	0.8-0.9	1

Passenger cars and vans account for 75% of the total emission of tyre wear particles (F.target = 0.75). Tyres with too low a pressure wear down more quickly. In 2009, consideration was given to implementing

[8] http://www.bandenportaal.nl/2014/05/16/italie-winterbanden-verboden-in-zomer

national regulations for tyre pressure in order to reduce tyre blowouts by lorries, but this was considered a very difficult proposition at the time (Minister van Verkeer en Waterstaat 2009). We assume that the same applies to the enforcement of legal regulations for tyre pressure for passenger cars.

Instead of implementing new regulations and enforcing them, collaboration took place with the transport sector to develop a system for optimising tyre pressure. A Tyre Pressure Monitoring System (TPMS) was introduced and driving with insufficient tyre pressure was reduced in the transport sector. The introduction of TPMS was successful because reducing instances of insufficient tyre pressure is also a cost-saving measure. The increasing level of attention paid in the transport sector to tire pressure is attested to by a 2012 report prepared by the Dutch Safety Board, which mentions that an inspection carried out by Goodyear in 2008 and 2009 revealed that 68% and 53%, respectively, of the lorries inspected were found to have low tire pressure. In 2010, that percentage was 12%. A study carried out by the RDW (Netherlands Vehicle and Driving Licence Registration Authority) in 2008 concluded that 15% of the lorry tyres inspected had low tire pressure. Our point of departure is therefore that the TMPS promotion measure applies only to passenger cars and vans. Such a measure must be accompanied by a public information/awareness campaign. It's difficult to assess the degree to which car owners will respond positively to such a campaign, in other words actually purchase a TPMS and react appropriately to a low-pressure signal.

There are various systems available (ZTA Expertise et al. 2015), which can in principle also easily be fitted into older cars (passenger cars and vans). Some systems can be fitted on or in the valve and others in the tyre. The signalling functionality varies from a simple warning light on the valve cap (indirect TPMS) to temperature and tire pressure readings displayed on the dashboard or on the smart phone (direct TPMS). These systems only function as signalling devices. The driver then has to pump up the tyres himself.

Since November 2014, under EU legislation 2010/48EC, TPMS has been a mandatory feature on all new registered passenger cars[9]. This feature was already mandatory starting in November 2012 for all new car models launched on the market. With regard to this measure, our point of departure is that cars with a build year older than 2014 will be fitted with a direct TPMS and that cars with a build year after 2014 with an indirect TPMS will be refitted with a direct TPMS. In the coming years, the number of cars with a build your older than 2014 will decrease from 79% in 2017 (data from Statistics Netherlands (CBS) February 2017) to roughly 25% over 10 years. Based on the CBS data, we can estimate that during the first 10 years after implementation of the measure, the percentage of cars fitted with a mandatory TPMS system will be roughly 50%.
It's estimated that 60% of cars on the road have a tyre pressure that is at least 10% too low, and that one third of these cars (i.e. 20%) have a

[9] http://www.tpms.nl/tpms-informatie/

tyre pressure that is 30% too low.[10,11] If the difference is 30%, the tyre abrasion will increase by an estimated 50% (Michelin 2010). Overall, this means that the measure at hand can reduce tyre abrasion by approximately 14% for cars with a sub-optimal tyre pressure. To take into account potential uncertainties, calculations were carried out using a range of 10% to 20% for abrasion reduction (F.abrasion = 0.8-0.9). Correct tyre pressure also reduces the risk of tyre blowouts, which are one of the causes of traffic jams. A higher tyre pressure results in increased fuel efficiency and tyre lifetime but has a negative impact on traffic safety. A correct tyre pressure ensures that the tyre has optimum shape and performance, which in turn minimises tyre abrasion.

T8 - Wheel alignment

Description: Including uneven tyre abrasion as a criterion for the periodic safety inspection of passenger cars and vans.

	F.target	F.road	F.vehicle	F.behaviour	F.abrasion	F.dispersion
T8	0.75	1	0.22-0.44	0.1-1	0.85-0.95	1

Wheel alignment and balance determine how the force and weight of the car are distributed over the tyres while driving. Wheel alignment is one way to influence the roadholding characteristics and stability of the car in curves on straight sections of road. Depending upon the desired driving characteristics of the car, different choices can be made in that regard during the design process.

Figure 9 Wheel alignment has a major impact on the roadholding characteristics of the car and on tyre abrasion. Photo: Milliken MX1 Camber Car 1960 driven by Bill Milliken (Brian Snelson).

[10] https://kiesdebesteband.nl/bandenspanning, 13-7-2017
[11] http://www.bandopspanning.nl/bandenspanning/wat-is-onderspanning/, 13-7-2017

The measure described in this section does not apply to the design of the car but to incidental disruptions of wheel alignment caused by collisions with other vehicles, posts or kerbs or potholes or bumps on the road or simply by old or worn-out wheel suspensions. A disruption of the wheel alignment and balance results in increased and uneven abrasion on the tyres and wheels suspension. Poorly balanced wheels also result in vibrations during driving. In addition, properly aligned and balanced wheels also have an effect on fuel consumption, tyre lifetime, and safety. Regular inspections of wheel alignment and balance can be one way of reducing tyre abrasion. One garage reports that approximately 60% of cars are not properly aligned[12]. A webpage that focuses on the US even goes so far as to report a percentage of 90% poorly aligned cars.[13] It is not clear whether the above information is also representative of the situation in the Netherlands.

Experts from the tyre sector estimate that poor alignment leads to an unnecessary increase in abrasion of 10%. No studies have been found that make it possible to directly estimate abrasion as a function of wheel alignment. However, a recent study is available that tested the effect of wheel alignment on energy consumption (Davari et al. 2017). In this study, in which tests were carried out on 'cambers' (vertical deviation) up to 1-2° and 'toes' up to 0.5° (deviations in the driving direction)[14], 7% higher energy consumption was found in certain phases of the NEDC (New European Driving Cycle) test. This applied to phases with a higher speed, for example on the motorway, and phases with higher and more frequent accelerations such as in the city.

With the help of the extended brush tyre model (EBM), the effect of wheel alignment was calculated over larger angles (Davari et al. 2017). This makes it clear that energy losses can be as much as approximately 50% for toes of plus or minus 10°. To estimate the relationship between wheel alignment and abrasion, we assume that energy losses are indicative of abrasion. It is not known how large the disruptions of toes and cambers are that are caused by incidents in real life. We assume that the angle disruption is of roughly the same size as the angles used by the manufacturers in the design, and we work with a range of values for abrasion between 5% and 15% (F.abrasion = 0.85-0.95) in order to take into account variations such as those in weight and dimensioning of the cars on the road and in road surface types. Additional research is needed to validate this assumption.

[12] www.profile-heuver.nl/balanceren/, 13 July 2017
[13] http://www.gordoncooleycoachbuilders.co.uk/images/Alignment.pdf, 13 July 2017
[14] The angles are within the usual range used by car manufacturers.

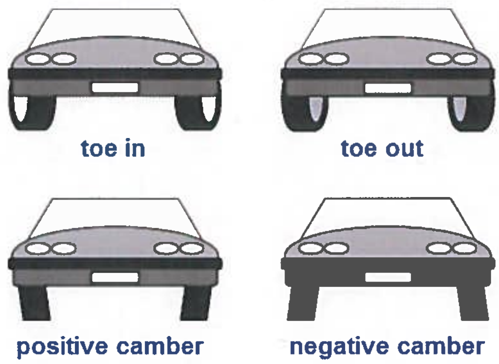

Figure 10 Wheel alignment: vertical deviations (cambers) and deviations in the driving direction (toes).

Regular inspections of vehicles aimed at guaranteeing safety and limiting emissions to the environment are set down in European regulations in Guideline 2014/45/EU (EC 2009). The tyres must be visually inspected, including a visual inspection to determine whether the tyre has suffered serious damage. A vehicle can fail to pass the test on these grounds. This provides possibilities for focusing on uneven wear of tyres. There are no criteria at present for approving or rejecting cars on the basis of an uneven wear pattern. However, if an uneven wear pattern is found to exist and the consumer is informed by the garage about the consequences of poor wheel alignment, the consumer can be encouraged to have the wheel alignment corrected.

A complete annual inspection with the help of wheel alignment equipment would cost a great deal more time and money. It would be more efficient to ensure that, during the visual tyre inspection that must take place anyway, attention is also paid to any uneven abrasion that may be present and to ensure that proper action is then taken.

For lorries and buses, as is the case with regard to the optimisation of tyre pressure, it would make sense to assume that sufficient attention is already being paid to wheel alignment and balancing for business reasons (cost savings).

European regulations require that the APK (periodic vehicle inspections) must be carried out annually for passenger cars older than 4 years, whereby a different schedule applies in the Netherlands to petrol cars (first inspection after 4 years), diesel cars (first inspection after 3 years), and taxis, ambulances and buses (first inspection after 1 year). For the calculations, we assume that all cars older than 4 years are subjected to an annual inspection. This applies to 74% of all cars (CBS Statline, 20 February 2017). Taking into account the different inspection schedules in the Netherlands, it would actually apply to a slightly higher percentage of cars, which would also lead to a slightly higher reduction potential. However, information to further refine this calculation is not available. In calculating the reduction potential, we also assume that the wheel alignment of 30% to 60% of the vehicles is suboptimal to such an extent that unnecessary extra tyre abrasion is noticeable. F.vehicle is then 0.74 x (30% to 60%) = 0.22 to 0.44.

T9 - Maximum speed limit

Description: Bringing maximum speed limit on motorways back to 100 km/hour.

	F.target	F.road	F.vehicle	F.behaviour	F.abrasion	F.dispersion
T9	0.35	0.9	0.6	0.99-1	0.7-0.8	1

This measure applies only to motorways and those vehicles that are allowed by law to travel faster than 100 km/hour, namely motorbikes, passenger cars and vans, which together account for 35% of the emissions of tyre wear particles (F.target = 0.35). The speed of a car influences tyre abrasion. According to a tyre manufacturer, a reduction of the speed limit from 120-130 km/hour to 100 km/hour would result in an estimated 20% to 30% longer tyre lifetime (Michelin 2010) (F.abrasion = 0.7-0.8). The speed limit on approximately 60% of Dutch motorways is 130 km/hour, and it is 120 km/hour on 30% of the motorways (F.road = 0.9).[15]

The personal driving style is an important factor for tyre abrasion. The same study carried out by Michelin estimates that 40% of car drivers have a very calm driving style, 50% a normal driving style, and 10% a sporting driving style. In calculating the reduction potential, we assume that the measure applies to 60% of the drivers of passenger cars, vans, and motorbikes (F.vehicle = 0.6) It is difficult to estimate to what degree the drivers will comply with a reduction of the speed limit. The measure applies to motorbikes, passenger cars, and vans.

A lower speed results in lower fuel consumption, lower CO_2 emissions, lower emissions of fine particles, and fewer traffic accidents. The disadvantages are a longer travel time and restriction of freedom.

T10 - Kilometre tax

Description: Introduction of a kilometre tax

	F.target	F.road	F.vehicle	F.behaviour	F.abrasion	F.dispersion
T10	0.35	0.2-0.5	1	0.75-0.9	1	1

We assume that the potential measure would be introduced in such a manner as not to affect buses, lorries, trucks, and special vehicles. The measure then applies to motorbikes, passenger cars, and vans on motorways, which together account for 35% of the emissions of tyre wear particles (F.target = 0.75). If fewer kilometres are driven, then tyre abrasion will also decrease. Tyre abrasion per kilometre driven remains the same (F.abrasion = 1), and the measure has no (additional) effect on the dispersion (F.dispersion = 1).

Traffic policy in the Netherlands is primarily focused on reducing traffic congestion, but it can also be effective in reducing the emission of fine

[15] nos.nl/artikel/2084794-op-deze-wegen-kun-je-vanaf-nu-130-km-u.html

particles, CO_2 and exhaust gases, noise pollution, traffic accidents, and tire abrasion. Automobility can be reduced by encouraging teleworking and flex work, carpooling, the use of public transport, and kilometre taxes. Efforts aimed at introducing a kilometre tax in the Netherlands (such as the 'Paying differently for Mobility' plan) have not yet been able to count on sufficient support, but such an approach has regularly been a topic of political discussion.[16] Such a measure has therefore been included in this report primarily to demonstrate what the effect of a kilometre tax would be on the reduction of tyre abrasion.

Depending on the manner in which the measure is implemented, a kilometre tax could lead to an estimated 10% to 25% reduction in the kilometres driven on motorways (Bruinsma et al. 2002), as a result of the effect of the measure on the behaviour of car users (F.behaviour = 0.75-0.9). It is not clear to what extent this quality of traffic, and the associated abrasion, would simply move to secondary roads. Such a phenomenon could potentially limit the projected decrease in tyre abrasion. On the other hand, the number of traffic jams would also decrease, together with a decrease in the number of braking and accelerating activities. The latter would have an additional favourable effect on tyre abrasion. These opposing effects could possibly cancel each other out, at least in part, but the end result cannot be quantified due to a lack of relevant information. The measure applies to motorbikes, passenger cars, and vans on motorways.

[16] Letter to the Minister of Infrastructure and the Environment, Mobility policy, No. 189, Parliamentary paper 31 305, no. 170

Appendix 3 Potential measures against emissions of paint particles

This appendix describes six potential measures that aim to reduce the generation or dispersion of paint particles, namely:

P1. Subsidies for research into degradation of paint
P2. Legally required guarantee period for paint
P3. Awareness campaign with regard to the rinsing of brushes
P4. Replacement scheme for old sanding machines
P5. Covenant on residual paint emissions
P6. Reduction of residual emissions from recreational vessels

The measures apply to a part of the emissions, as indicated in Table 7.

Table 6 Origin and size of the emissions and the scope (X) of the potential measures.

		Total	P1	P2	P3	P4	P5	P6
Professional construction	Maintenance	130	X	X		X		
	Wear	210		X				
Do-it-yourselfers	Maintenance	70	X			X		
	Wear	60						
	Rinsing	20			X			
Shipyards	Maintenance	90	X				X	
	Wear	90						
Marinas and storage facilities	Maintenance	20	X			X		X
	Wear	4						
Total (tonnes/year)		690	310	340	20	220	90	20

[1] Range is a consequence of uncertainty in the treatment yield of water treatment plants (also see footnote on page 15).
[2] Abrasion of paint on ships built or serviced in Dutch shipyards.

An overview of the estimated reduction of emission is presented in Table 7. The measures and the reduction potential are explained further on in this appendix. The estimation of emissions and the reduction potential of the measures is subject to uncertainties. This was taken into account by indicating uncertainty margins and rounding off the results to one significant figure.

Table 7 Estimated emission reduction (in tonnes/year) of paint measures.

	Total	Soil	Water (direct)	Sewer system	Water (total)
P1	60 (3-130)	50 (2-90)	30 (1-60)	20 (1-30)	30 (1-60)
P2	20 (2-30)	9 (1-20)	1 (<1 - 1)	6 (1-12)	4 (<1-8)
P3	9 (2-20)	0	<1	9 (2-20)	5 (<1-9)
P4	70 (10-100)	40 (7-70)	5 (1-10)	20 (4-40)	20 (2-30)
P5	50 (9-90)	50 (9-90)	50 (9-90)	0	50 (9-90)
P6	9 (2-20)	9 (2-20)	9 (2-20)	0	9 (2-20)

P1 - Subsidies for research into degradation of paint

Description: Providing a research budget for a European call to develop paint that can be degraded in a controlled manner.

The controlled degradation of paint particles can prevent the formation of microplastic. At present, there are no paint products available that guarantee long-term quality and that are also degradable in a controlled manner. This would mean that no increased degradation takes place during the lifetime of the paint, but that it takes place during the removal of the paint or afterwards Due to the lack of relevant data, we have assumed that an innovative product that combines both these characteristics could result in a 25% reduction of microplastic in all sectors that use paint. As the measure is not mandatory, we take into account that only 10% of the reduction potential that is technically possible could be realised, depending upon the choices made by consumers. The calculation of the reduction potential to water is presented below:

$$Reductiepotentieel = A \times B \times C$$

In which:

$A = reductie\ van\ verfdeeltjes\ in\ milieu\ door\ afbraak = 25\%\ (10 - 40\%)$
$B = gedragsfactor (0.1 - 1)$
$C = emissie\ naar\ water\ zonder\ maatregel\ (zie\ \text{Table 6})$

P2 - Legally required guarantee period for paintwork

Description: Introducing a legally required guarantee period for paintwork.

A legally required guarantee period for paintwork could encourage the paint chain to work with a longer lifetime for paintwork, longer maintenance intervals, and fewer emissions of paint wear particles and paint sandings. Measures that could lead to a longer lifetime of paintwork include choosing higher-quality paint, better preparation of the surfaces to be painted, and proper paint application. The maintenance sector association 'OnderhoudNL' has already implemented a guarantee period. The measure discussed here targets the professional painters who are at present not represented by OnderhoudNL. This represents 15% of the professional market. The assumption is that this measure will lead to a 50% reduction of emissions as a result of a longer interval between paint maintenance rounds.

The calculation of the reduction potential to water is presented below:

$$Reductiion\ potential = A \times B \times C \times D$$

in which:

$A = average\ reduction\ of\ abrasopn\ due\ to\ longer\ maintenance\ intervals = 40 - 60\%$
$B = marktet\ share\ of\ painting\ companies\ that\ are\ not\ members\ of\ the\ sector\ specific\ association = 15\%$
$B = behavioural\ factor (0.1 - 1)$
$D = emission\ without\ any\ measure\ (see\ \text{Table 6})$

Whether the reduction is actually realised will depend on many uncertain factors, such as the results of the study into paint degradation, the market introduction of such a paint and its price, and the motivation of the consumer to actually purchase this paint.

P3 - Raising public awareness with regard to rinsing of brushes

Description: Campaign aimed at encouraging consumers to deal appropriately with used brushes and rollers.

The practice of cleaning used brushes and rollers in the sink still takes place in the Netherlands. Water-based as well as oil-based paints are chemical products that should not be flushed down the sink. Preventing this practice will reduce the quantity of microplastic, as the paint residues on the brush or roller are considered to be microplastics. There is a link between this and the 'Not in the Sewer' campaign of RIONED that provides information on the appropriate use of the sewer system.[17] There are various websites that provide guidelines for cleaning and storing brushes. Making more information available for a wider audience about the cleaning of brushes could possibly reduce the above emissions. The effectiveness of the measure is difficult to estimate and depends to a large extent on how frequently the information is provided and in what manner (also see section 4.3). A range of 10% to 100% was used for the calculation of the emission reduction.

The maximum reduction potential of the emission to water is 4 to 9 tonnes/year, assuming that all consumers were to adjust their behaviour. The emission to sewage water treatment plants would be reduced by a maximum of 16 tonnes/year.

P4 - Regulations for replacing older sanding machines

Description: Providing a subsidy for manufacturers of sanding machines for introducing a replacement scheme for older sanding machines with dust removal systems.

The sanding down of older paint layers is one of the primary causes of the emission of paint particles. Inhalation of paint dust poses a health risk. The newer models of sanding machines with dust removal systems remove approximately 90% of paint dust compared to 70% in the older models.[18] For the do-it-yourself sector and the sanding of recreational vessels, it is assumed that the less than professional use of sanding machines will result in 50% less paint dust being removed. The emission reduction for professionals in the construction sector is therefore 67% and for the do-it-yourself sector 33%. The measure is not applicable to shipyards, as sandblasting is used there instead of sanding. The calculation of the reduction potential to water is based on outdoor paint application. Emissions to soil are not presented here, but they have been taken into account (Verschoor et al. 2016). As the measure is a voluntary one, an effectiveness of 10% to 100% (behavioural factor = 0.1-1) is taken into account.

[17] http://www.nietinhetriool.nl/
[18] Personal communication (Maaike le Feber, TNO).

$$Reductiepotentieel\ (water) = (A \times B + C \times D) \times E$$

in which:

$A = reduction\ of\ dispersion\ of\ paint\ sandings\ in\ the\ DIY\ sector = 33\%$
$B = \ emission\ to\ water\ by\ DIT\ sectorwithout\ any\ measure$
$C = reduction\ in\ dispersion\ of\ paint\ sandings\ by\ professionals\ = \ 67\%$
$D = gbehavioural\ factor$ 0.1 − 1
$E = emission\ to\ water\ by\ professionals\ without\ any\ measure$ (*zie* Table 6)

P5 - Covenant on residual emissions at shipyards

Description: Covenant with the sector aimed at finding solutions for further minimising emissions at shipyards.

When old paint layers are sandblasted, a small part of the paint particles still ends up in the environment. Techniques for sandblasting and coating ships at shipyards art set down in Best Available Techniques Reference documents (BREF). Members of the trade association for the Dutch maritime technology sector (NMT) work according to the techniques described in BREF. The present BREF (2007) documents are being updated by the European Integrated Pollution Prevention and Control (IIPC) bureau. The new BREF will be published in 2019. Supervisory government bodies use the BREF document as a basis for granting an all-in-one permit for physical aspects. The all-in-one permit then serves as the reference point for (environmental) inspections at shipyards and enforcement activities. Within BREF, there are various methods for applying paint and removing coatings. As the present working method has been developed to the point where an estimated 97.5% of emissions are prevented, further emission reduction will not be a simple matter. Collaboration with the sector aimed at investigating where and under which circumstances emissions still occur can provide further insight into this matter. On this basis, improvements can be proposed in techniques or business operations, and the associated costs and benefits can be further investigated. By making this research part of a covenant with the government, it will be possible to enter into concrete agreements.

In making the calculations, a reduction potential of between 10% and 100% was taken into account.

P6 - Reduction of paint emissions from recreational vessels

Regulations are in force for recreational vessels that limit paint emissions during vessel maintenance activities. Section 4.6.6 of the Activities Decree (AB) contains regulations on maintenance, repair, and jetting of recreational vessels. These regulations aim to prevent environmental pollution. Maintenance and jetting activities for boats are not always done in a marina. The section applies to maintenance carried out inside a marina as well as activities carried out on a separate storage site.
The residual emissions concerned are estimated at 18 tonnes per year, but it is not clear how these can be reduced. We recommend consulting with the HISWA (voluntary trade association for water sports), which represents the interests of the recreational water sports sector.

In making the calculations, a reduction potential of between 10% and 100% was taken into account.

Appendix 4 Measure in relation to abrasive cleaning agents

European ban on products with microplastics

Description: Striving for a European ban on the use of microplastic in abrasive cleaning agents

With an estimated emission to water of 1.2 tonnes per year in the Netherlands, abrasive cleaning agents represent a minor source. According to the Dutch Association of Soap Manufacturers, which represents 90% of the market, their members produce and market no products with microplastics. A brief tour of supermarkets confirmed this assertion. However, products containing microplastic can be acquired via the Internet (from national or foreign sources), or they can be supplied as maintenance products together with the delivery of new kitchens for example. We have not checked the scale of such activities.

Due to the open European internal market, a ban on microplastic in abrasive cleaning agents can best be dealt with on a European level. Via this measure, the Netherlands would make an effort to put this topic on the European agenda. The time period necessary to ensure that such a measure becomes effective is quite long. The effectiveness of the measure will be practically 100%.

The calculation of the reduction potential to water is presented below:
$Reductiepotential\ (water) = A \times B = 1{,}2\ tonnes/year$

in which:
$A = reduction\ via\ European\ ban = 100\%$
$B = emission\ to\ water\ without\ any\ measure\ = 1.2\ ton/jaar$

Appendix 5 MCA scoring method

Criteria	Description of the scores	Max. score
Environment & Safety:		15
Energy consumption	Less energy consumption is more favourable: -3 = more 0 = unchanged 3 = less	3
Consumption of materials	Less consumption of materials is more favourable: -3 = more 0 = unchanged 3 = less	3
Chemicals	More emission reduction is more favourable: 1 = reduction <1 tonne/year 2 = reduction between 1 and 10 tonne/year 3 = reduction >10 tonne/year	3
Intervention point	Prevention is more favourable than end-of-pipe measures: 0 = cleaning (end-of-pipe) 1 = minimising dispersion 2 = preventing emission of microplastic 3 = preventing generation of microplastic	3
Safety	Increased safety is more favourable: -3 = negative impact on safety 0 = no effect 3 = positive impact on safety	3
Practical feasibility:		9
Enforcement	Is enforcement necessary, and is there an enforcement method available? 1 = necessary but not available 2 = necessary and available 3 = no enforcement necessary	3
Implementation period	A short implementation period is seen as being more feasible: 1 = >10 years 2 = 3 -10 years 3 = <3 years	3
Scope	A national approach is seen as being more feasible: 1 = international 3 = national	3

Scoring the various measures and weighing the resulting scores are necessary steps for classifying/grading the proposed measures. In order to grade the assessment results, it's necessary to determine how much weight is given to each criteria in calculating the end score of a measure. This is realised by assigning a weighting factor to each criterion score.

The choice to apply a specific weighting factor is a value judgement. The choice of weighting factors as well as the resulting classification of the measures should be discussed within the framework of independent policy discussions. It is therefore possible that the choices made in this report with regard to weighting differ from the positions taken by the policymakers. For example, policy makers may attach greater importance to specific criteria and weigh them more heavily in the end scores. This report assigns equal weighting factors to the criteria categories *environment & safety* and *practical feasibility*. The reason for this is that no preference for either of these categories has yet become available from policy discussions. However, it is quite simple to adjust the weighting factors on the basis of political decisions that may be taken.

Calculation of the MCA end score
The MCA end score is calculated in several steps. In the first step, the criteria scores within the categories *environment & safety* and *practical feasibility* are totalled separately. The scores for the categories are calculated as follows:

- $Score\ \text{"}Environment\ and\ safety\text{"}\ (max.\,15\ points) = \sum score\ (Energy\ Use + Materials\ Use + Chemical\ Use + Safety + Intervention\ point)$
- $Score\ \text{"}Feasibility\text{"}\ (max.\,9\ points) = \sum score\ (Enforcement + Implementation\ period + Scope)$

The MCA end score is expressed on a scale with a maximum of 10, whereby a score of 10 is assigned to a measure that scores most favourably with regard to consequences for the environment, safety, and practical feasibility. As explained earlier, the criteria *reduction potential* and *cost-effectiveness* are not included in the MCA end score but presented separately. In calculating the MCA end score, the scores for *environment & safety* and *practical feasibility* are assigned the same weight. The MCA end score is calculated as follows:

- $Endscore = \frac{Score\ \text{"Environment and safety"} + \text{Score "Feasibility"} \times {}^{15}/_{9}}{3}$

Appendix 6 MCA scores for 'environment & safety' and 'feasibility'

The scores have been determined by RIVM. An initial scoring round has taken place on the basis of literature, talks with sectoral associations and policymakers, and information available on the Internet. This was followed by a feedback round, and the scores were adjusted if new information became available.

Code	Description	Energy use	Material use	Chemical use	Intervention point	Safety	Environment and safety score	Enforcement	Implentation period	Scope	Feasibility score	Total score
T1	Legal threshold value for tyre abrasion	3	3	2	3	0	11	1	2	1	4	**5.9**
T2	Tyre label with tyre abrasion indicator	3	3	2	3	0	11	1	1	1	3	**5.3**
T3	Legal threshold value for road surface wear and tear	3	3	1	3	0	10	1	1	3	5	**6.1**
T4	Sustainability tool for road surface	3	3	1	3	0	10	3	1	3	7	**7.2**
T5	Street cleaning campaigns in urban areas	-3	-3	1	1	0	-4	3	3	3	9	**3.7**
T6	Ban on the use of winter tyres in summer	3	3	1	3	3	13	1	3	3	7	**8.2**
T7a	TPMS in all cars	3	3	3	3	3	15	3	2	3	8	**9.4**
T7b	TPMS in older cars (built before 2014)	3	3	3	3	3	15	3	2	3	8	**9.4**
T8	Including wheel alignment in periodic vehicle inspections	3	3	1	3	3	13	3	3	3	9	**9.3**
T9	Reducing maximum speed limits	3	3	1	3	3	13	2	2	3	7	**8.2**
T10	Kilometre price	3	3	1	3	3	13	1	2	3	6	**7.7**
P1	Subsidies for research into degradation of paint	3	3	2	1	0	9	3	3	3	9	**8.0**
P2	Legally required guarantee period for paintwork	3	3	1	3	0	10	1	2	3	6	**6.7**
P3	Campaign aimed at raising public awareness with regard to rinsing of brushes	0	0	1	2	0	3	3	3	3	9	**6.0**
P4	Regulations for replacing older sanding machines	0	-3	1	1	3	2	3	3	3	9	**5.7**
P5	Covenant on residual emissions in marinas	0	0	3	1	0	4	2	2	3	7	**5.2**
P6	Raising awareness of residual emissions in the recreational vessel sector	0	0	1	1	0	2	3	3	3	9	**5.7**
ACA	Ban on products with microplastics	1	1	1	3	0	6	1	2	1	4	**4.2**

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