Whitepaper

Microplastics are everywhere: 70% reduction achievable

In the Netherlands, the main sources of microplastics are from tyre abrasion, packaging, and the use of agricultural foil

Authors
Jan Harm Urbanus
Andrea Brunner, Arjen Boersma,
Sieger Henke, Ingeborg Kooter,
Sietske Lensen, Luke Parker,
Anna Schwarz, Pieter Imhof,
Ardi Dortmans, Marinke Wijngaard

TNO innovation for life

Microplastics are everywhere: 70% reduction achievable

Microplastics are potentially harmful to humans and the environment

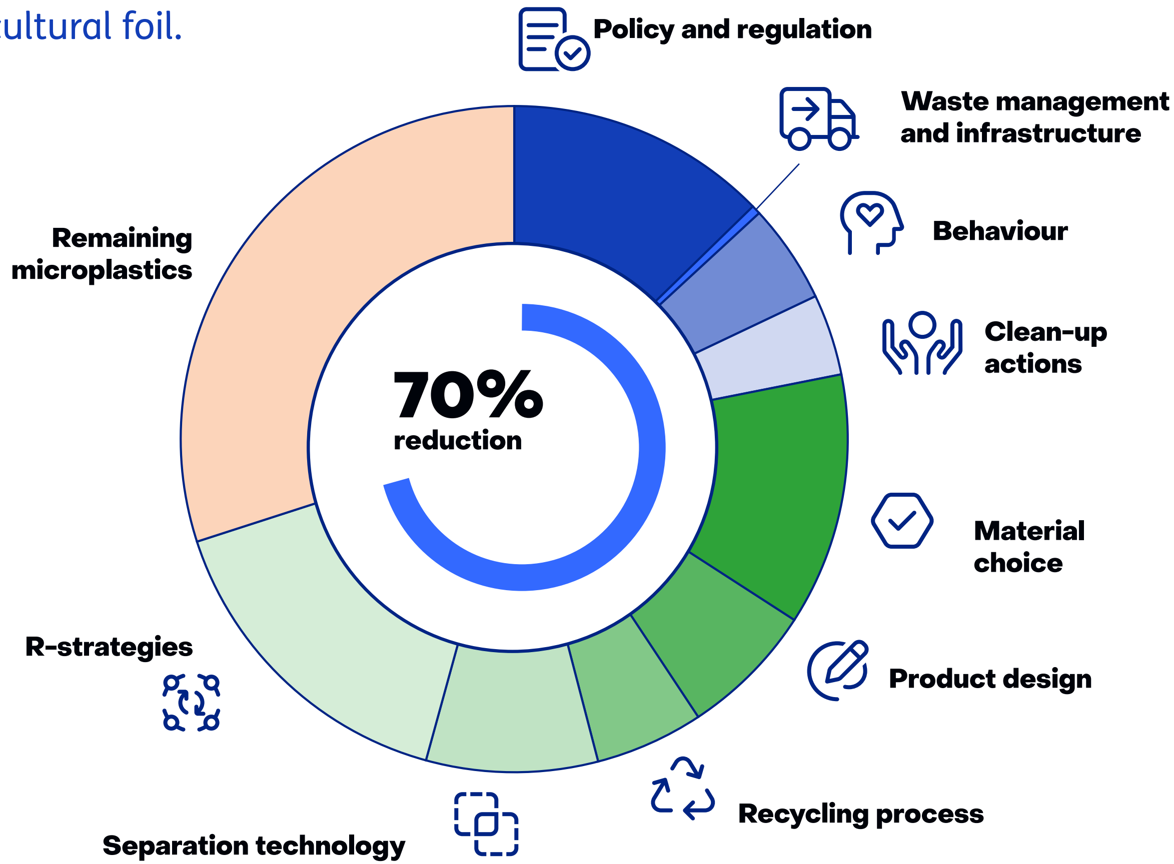
The 'precautionary principle' applied by the Dutch government prescribes minimising the formation and spread of microplastics.

Microplastics can now be found everywhere, and are present in increasing quantities in the environment. In the Netherlands, the main sources of microplastics are from tyre abrasion, littering (packaging), and the use of agricultural foil.

The present publication shows that a combination of mitigation strategies will make possible a 70% reduction in microplastics by 2050 (and 37% by 2030), even with the increasing use of plastics. This will require cross-border cooperation. The potential damage from microplastics makes it essential to achieve this reduction.

Achieving it requires the following measures: extending the deposit systems on returnable plastic items, realisation and roll-out of 'R strategies', encouraging the cleaning-up of litter, accelerating innovations in materials, and research into improved recycling technology.

Jan Harm Urbanus
Andrea Brunner, Arjen Boersma, Sieger Henke, Ingeborg Kooter, Sietske Lensen, Luke Parker, Anna Schwarz, Pieter Imhof, Ardi Dortmans, Marinke Wijngaard



Summary

Microplastics are man-made (anthropogenic), persistent, ubiquitous, and potentially harmful. According to the precautionary principle, we must minimise exposure to them.

Problem
In the Netherlands, packaging, car tyres and agricultural foil are the biggest contributors to microplastics, and the problem is only going to increase as we move towards 2050.

Solutions
This problem can be solved for up to 70%, provided government, industry, and consumers take timely action to enact legislation, develop innovative materials and technology, and reduce the consumption of plastics.

Unresolved downsides of plastic
Plastics contribute to a sustainable society (see TNO's 'Don't waste it!' publication (2020)), but they also have unresolved downsides, including microplastics. These solid particles, smaller than 5 millimetres, are deliberately used in products, are created through wear and tear during use, and are formed through the degradation of plastic waste present in the environment.

Persistent
Microplastics originate from anthropogenic plastics, are to a very large extent persistent, are increasingly found in the environment worldwide, and have recently been shown to even enter the human body. Unfortunately, there is insufficient information on the exposure of humans to microplastics and the impact they have for us to be able to make well-considered risk assessments. The Dutch government therefore applies the precautionary principle, meaning that the use, formation, and spread of microplastics must be minimised. The Dutch approach is thus in line with the strategy adopted by the EU.

Systemic understanding
Mitigating the problem of microplastics requires a systemic understanding of the entire life cycle of plastics: their production, use, and end-of-life phase. Given that such an understanding has so far been lacking, TNO – based on validated databases and scientific publications – has designed a model that calculates which sectors make the greatest contribution to the formation of microplastics and in which environmental compartments they subsequently end up. The microplastics model shows that the packaging, automotive, and agriculture sectors make the largest contributions in the Netherlands.

Mitigation strategies
Various mitigation strategies, either under development or already partially being implemented, can contribute to the solution: policy, choice of materials, product design, recycling and separation technology, people's behaviour, waste management, and clean-up campaigns. TNO has calculated the effectiveness of 17 mitigation strategies using the microplastics model and concludes that the Netherlands has much to gain from rolling out the 'R strategies' – Refuse, Rethink, Reduce – and associated technological, marketing, and behavioural concepts. A major contribution can also be made by banning Single-Use-Plastics (SUPs) and extending the system of disposal fees and deposits on returnable plastic items so as to positively influence 'throw-it-away' behaviour on the part of consumers. The same is true of the use of innovative materials that reduce the formation of microplastics resulting from car tyres and packaging. By implementing these mitigation strategies, a 70% reduction in microplastics by 2050 (37% by 2030) is possible, even in a scenario where plastics consumption increases.

Public support
Public support is needed in order to accomplish this mission. We carried out a qualitative analysis of the Dutch action plan based on the costs/benefits per mitigation strategy and the time required for carrying it out. The most achievable strategies are to further roll out the deposit system principle, implement the Refuse, Rethink, Reduce R strategies, accelerate innovations in materials, and carry out research into improved recycling technology. For other mitigations, further development of policies and business models will be important. It is essential for the Dutch government to play a coordinating role in developing and implementing these mitigation strategies in cooperation with all the other stakeholders.

Contents

Microplastics: minimising emissions into the environment and humans

Don't waste it!
Plastics have demonstrable added value for society (see TNO's 'Don't waste it!' publication (2020))[1]. Less weight saves on fuel in transport. Plastic packaging extends the shelf life of food products. Using plastics in textiles reduces the consumption of water that is otherwise required for growing cotton. Resistance to rot and corrosion reduces waste in the construction sector. But the downside of all this is that microplastics are released during production, use, recycling, and the end-of-life phase of plastics. These are solid plastic particles, smaller than 5 millimetres, in all shapes and sizes[2].

We distinguish between primary and secondary microplastics. Primary microplastics are deliberately added to products such as cosmetics (toothpaste, scrubs, glitter), (industrial) detergents, seeds, paints, and coatings because of the functions that they have. Secondary microplastics are created unintentionally through wear and tear (from clothing and tyres), degradation (during recycling), or aging of plastics. For instance, litter at the side of the road, on the beach, and in the ocean can fragment into microplastics due to the effect of sunlight (UV), friction, temperature fluctuations, and in the presence of chemicals (including salt) and micro-organisms.

Ethical perspective
A number of studies show that microplastics are not only found everywhere in the environment but also in people's lungs[3] and blood[4]. As SAPEA[5] (Scientific Advice for Policy by European Academies, 2019) and the WHO[6] (World Health Organization, 2022) concluded after an extensive review of the scientific literature, the risk this poses to human health is still largely unknown. But from an ethical perspective alone, the harm caused by microplastics to the integrity of the environment and the human body is unacceptable, whether or not the risk has been proven. Moreover, the 1992 Rio Declaration on Environment and Development[7] requires that, because plastic is a man-made product and to a very large extent persistent, the precautionary principle must be applied[8]. This will also prevent unknown future problems. Action is needed to minimise exposure to microplastics.

> Because the risk posed by microplastics is unknown, the precautionary principle must be applied

Higher risk profile
The projected quadrupling of the use of plastics by 2050[9] automatically leads to a higher risk profile. SAPEA therefore recommended mitigating exposure to microplastics. The European Commission then followed up the 'EU Strategy for Plastics in the Circular Economy'[10] with a new Circular Economy Action Plan[11] containing specific legislative and regulatory pointers for reducing emissions of non-intentional microplastics into the environment and humans. The objective is a 30% reduction by 2030. At the same time, the European Chemicals Agency (ECHA) has been asked to propose legislation restricting the use of deliberate (primary) microplastics[12]. The Netherlands adheres to the precautionary principle and has endorsed the EU objective. Moreover, it supports additional EU legislation to minimise the formation and spread of microplastics[13].

In the present publication, we outline the Netherlands' action plan for severely mitigating microplastics.

> **Microplastics are solid plastic particles, smaller than 5 millimetres, in all shapes and sizes**

Systemic overview needed across the chain to assess effectiveness of measures

TNO's microplastics model

The stated objective and proposals are the first steps towards a comprehensive package of legislation, measures, technology, and economic incentives to mitigate exposure to microplastics. All that is lacking is a systematic overview as the basis for designing interventions. As a result, we may perhaps develop the wrong strategies, thus losing both time and money. TNO has therefore developed a model[14] that systematically describes exposure to microplastics. It provides specific guidelines for evaluating the effectiveness of current and future measures (see box 'TNO's microplastics model').

TNO's microplastics model systematically describes exposure to microplastics, provides an understanding of the magnitude of the problem, and makes evaluation of the effectiveness of current and future measures possible.

Material Flow Analysis

TNO's microplastics model systematically describes exposure to microplastics, provides an understanding of the magnitude of the problem, and makes evaluation of the effectiveness of current and future measures possible.

The model employs a cumulative Material Flow Analysis (MFA) framework that describes the various steps in the plastics value chain. The model breaks down the value chain into ten sectors and the eight most common types of polymer.

For each country, we used available data (on a mass basis) on plastics production, consumption (including life cycle), plastic waste collection, and waste disposal (landfills, recycling, and incineration). Added to this framework are data on the formation of (secondary) microplastics at different points in the value chain, as well as information on their distribution across environmental compartments (soil, water, air, and organisms). This information is of an experimental and theoretical nature and based on scientific literature (>50 publications).

A standard MFA model as shown in Figure 1 on page 7 basically describes a one-year cross-section. Plastics have been produced, used, and thrown away on a large scale since 1951, resulting in the unavoidable formation of microplastics. Moreover, plastics lying in the environment take a long time to fully degrade[15] and thus don't cease to act as a source of secondary microplastics.

Material Flow Analysis-model (MFA)

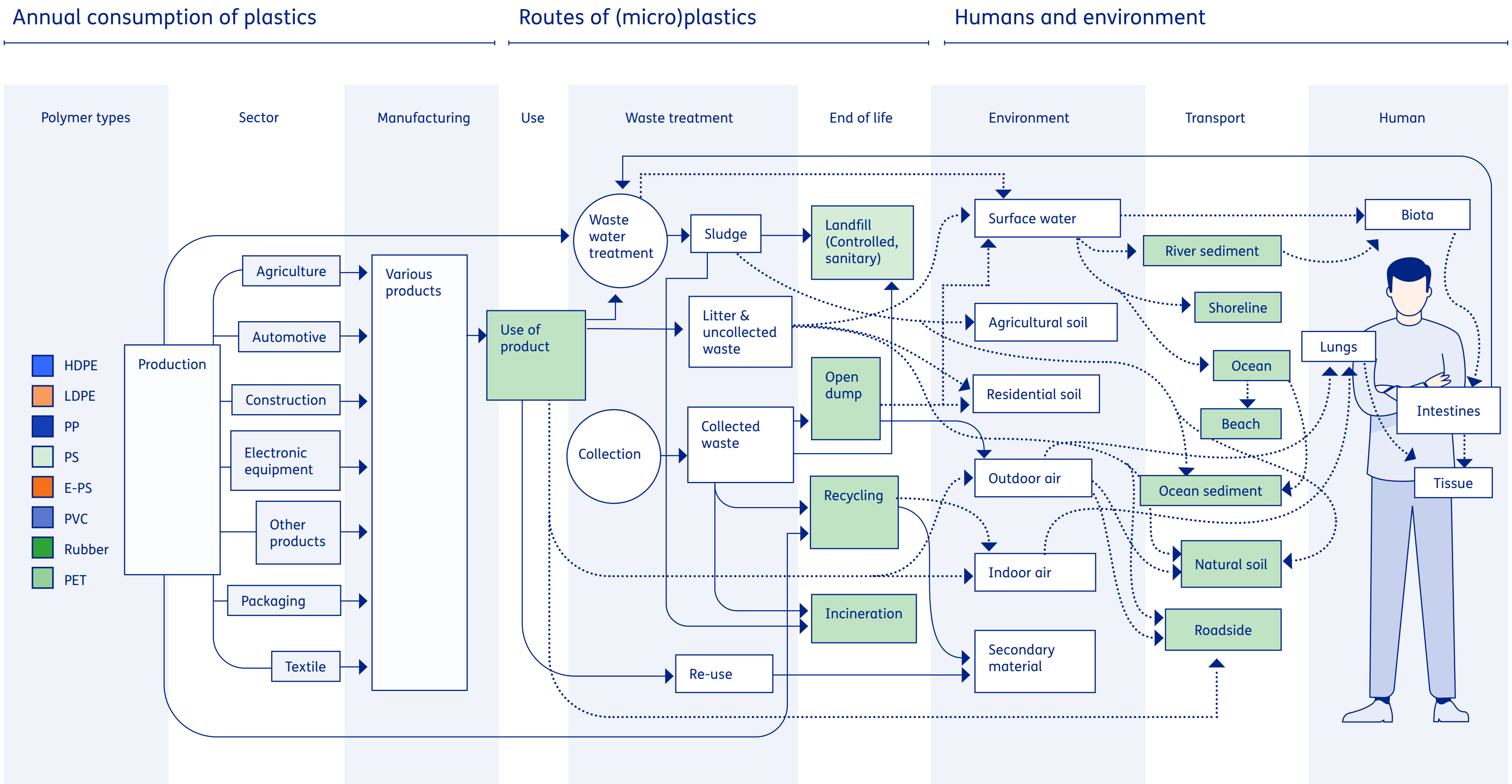


Figure 1. Simplified representation of the Material Flow Analysis (MFA) model. Figure 1 illustrates how a standard MFA works: on the left-hand side of the figure is the annual consumption of plastics (see Figure 2 for the Netherlands), in the middle the routes along which the (micro)plastics 'travel', and on the right the places in humans and the environment where (micro)plastics end up. Source: TNO.

Microplastics accumulate constantly over the years in various environmental compartments

Microplastics accumulate constantly over the years in various environmental compartments. To incorporate this legacy reality, the MFA model was made cumulative, with a starting point of 1951 (based on historical data and an average annual growth rate of 4%).

TNO's MFA model contains data not only for the Dutch context but for the entire world. The data come from a variety of European and international databases[16,17,18] and are supplemented where necessary by estimates based on comparable countries, according to the subdivision into four income brackets.

The consolidated data on the annual formation of microplastics and the environmental compartments in which they end up are shown in Figures 3 and 4 (page 9).

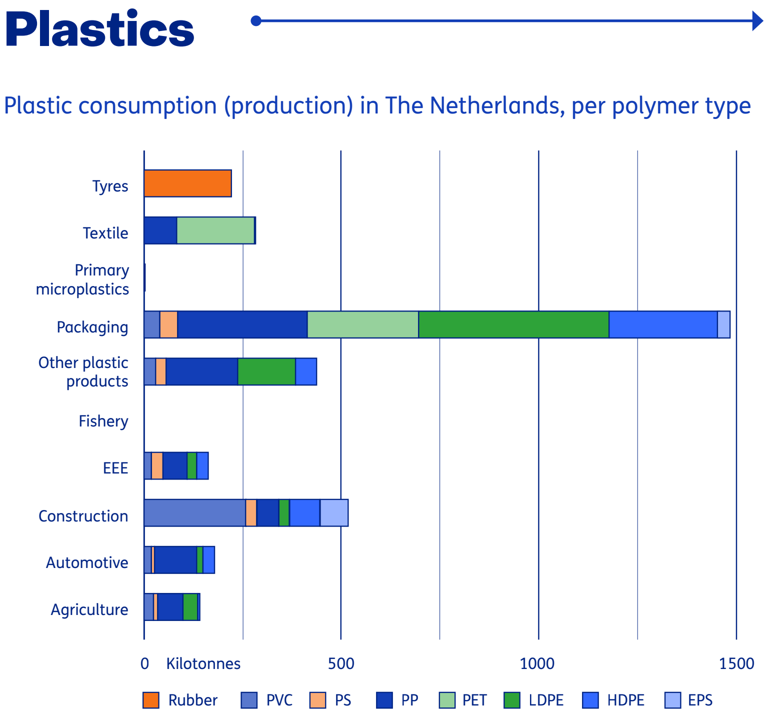


Figure 2. Netherlands' consumption of plastics, for 10 sectors (y-axis) and for 8 polymer types (colour). Source: TNO.

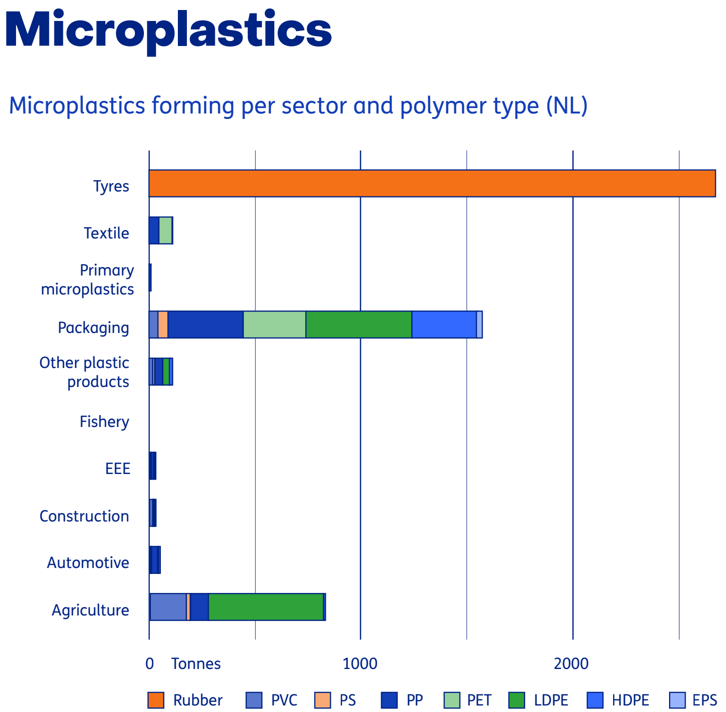


Figure 3. Annual microplastics formation for 10 sectors (y-axis) and for 8 polymers (colour). Source: TNO.

Biggest sources of microplastics: car tyres, packaging and agricultural foil

Outcome
The model shows that rubber tyres are the largest source of annual microplastics emissions in the Netherlands, whereas rubber only accounts for 6% of total consumption of plastic (see Figure 2: 218 kilotonnes of rubber versus 3,400 kilotonnes of plastics). This is due to the high degree of abrasion during use (10-20% over the lifespan)[19]. The rubber microplastics mainly end up in roadside verges and remain there. Unlike most plastics, rubber does degrade; there are indications that annually around 40% degrades completely,[20,21] although follow-up research is needed to clarify this further[22]. The effects of this degradation can only be observed in the cumulative model.

Other sectors contributing significantly to annual microplastics emissions are agriculture and the packaging industry. The microplastics that they create largely end up in the soil through improper disposal of plastics at the end of their use. For example, some plastic products are not disposed of but left in the environment, where microplastics form due to degradation. In the case of textiles, microplastics are created through wear and tear during use. They find their way into the air or into the sewers. What is also striking is that the accumulation of microplastics in (surface) water is an order of magnitude less than their accumulation in soil.

Microplastics & environmental compartments (NL)

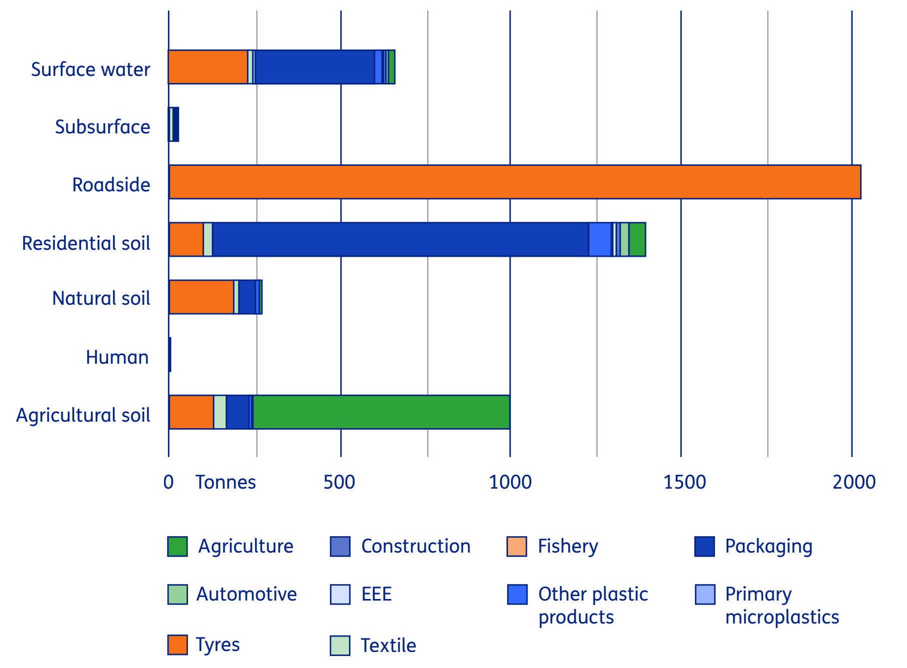


Figure 4. 7 Environmental compartments (y-axis) where microplastics end up, differentiated for ten sectors (colour). Source: TNO.

Delaying mitigation leads to undesirable accumulation of microplastics in the environment

The cumulative MFA model allows projections to be made towards 2030 and 2050 of the quantity of microplastics accumulating in the various environmental compartments.

To understand the extent of the problem as well as the scope for solutions, two scenarios were calculated: 'Maximum (MAX)' and 'Production Stop (STOP)'.

In the MAX scenario, we assume a more or less constant growth in plastics consumption (4% per year), with the corresponding emission of microplastics. This is in line with the plastics industry's projections predicting growth by a factor of 3 to 4 towards 2050.[23] We have also assumed for this scenario that current plastics remain in use, that consumption and end-of-life cycle behaviour do not change, and that the current distribution of plastic waste between landfills, recycling, and incineration does not change significantly.

In the STOP scenario, production of both new and recycled plastics will cease in 2022. For a few sectors, such as packaging and cosmetics, this means that the use of plastics will also cease almost immediately. For other sectors (tyres, automotive, construction, infrastructure), plastics will remain in circulation for a long time and thus continue to generate microplastics. In both scenarios, the additional emissions come on top of the formation of (secondary) microplastics through degradation of plastics that are already in the environment and have been exposed to the elements there for a long time.

Figure 5 shows cumulative microplastics emissions (tonnes) per sector for the Netherlands. The green columns represent the current accumulation (i.e. from 1951 to 2022). As an example, there are currently some 130 kilotonnes of microplastics from packaging in Dutch roadsides, fields, landfills, and more.

Accumulation of microplastics in The Netherlands, per sector (2050)

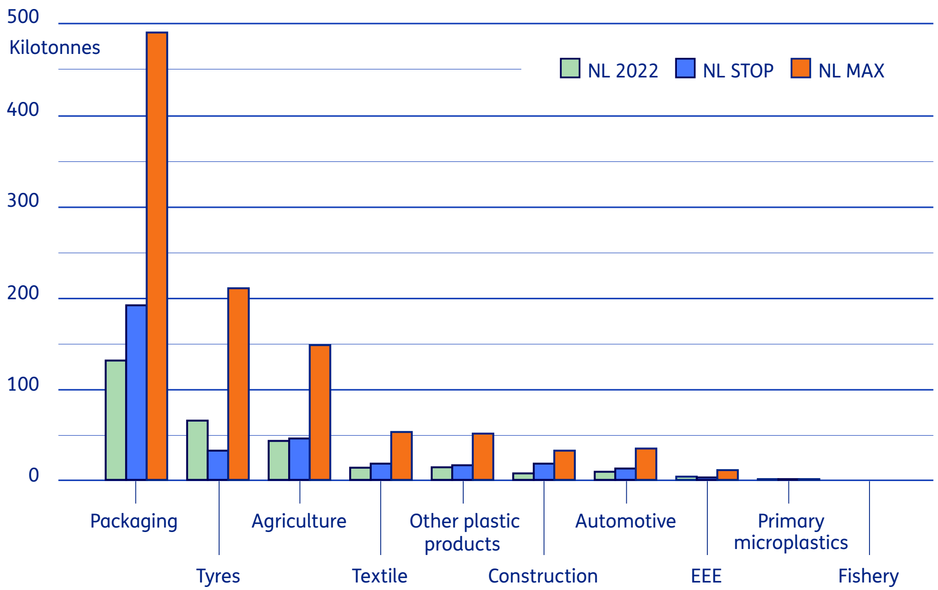


Figure 5. Accumulation of microplastics in the Netherlands, per sector, in 2050. The orange columns represent the 'Maximum (MAX)' scenario, the blue columns represent 'Production Stop (STOP)'. The green columns show the accumulation per sector up to and including 2022. Source: TNO.

There are some 130 kilotonnes of microplastics from packaging in the Dutch environment

The orange columns correspond to the MAX scenario described above. This is therefore the quantity of microplastics that, according to this scenario, will still enter the environment per sector until 2050. For packaging, this means the addition of almost 350 kilotonnes on top of what is already in the environment. The car tyre and agricultural sectors also contribute significantly in the MAX scenario.

The blue columns correspond to the STOP scenario. This is the quantity of microplastics that will still be emitted over the next 30 years, despite production having ceased. In the case of packaging, for example, some 60 kilotonnes of microplastics will be added, mainly due to degradation of products already in the environment.

The STOP scenario is socially unacceptable because there are no good sustainable alternatives to plastics (see TNO's 'Don't waste it!' publication (2020)[24]). As an illustration: in the automotive sector, a car without plastics would be technically impossible and also considerably heavier, leading to additional fuel consumption, CO_2 and particulates. Figure 5 shows that even in the STOP scenario, which is undesirable from a sustainability perspective, there is still a significant accumulation of microplastics in the environment. STOP is therefore unrealistic, but so is MAX; the actual situation in 2050 will lie somewhere between these two extremes. Given the current aims and developments in policy and behaviour, it will be closer to MAX than STOP.

Society cannot afford not to intervene.

Measures to minimise exposure to microplastics are urgently needed.

What can we actually do?

Maximum deployment of the 17 mitigation strategies leads to a maximum reduction of 70% microplastics by 2050.

Various mitigation measures are proposed not only in the EU's 'Strategy for Plastics in the Circular Economy'[25] but also in popular and scientific literature. These can be grouped into nine categories (see Table 1). The proposed measures need to be viewed in the context of their function. A microplastics solution for car tyres that leads to poor grip on the road or to packaging providing less protection is unrealistic.

Below, we give 17 examples of realistic, potentially effective mitigation strategies, broken down across the nine categories.

The mitigation strategies are listed in blue **followed by the corresponding assumptions in bold.**

The TNO model provides systemic means for evaluating these mitigations and also for developing new strategies. The effectiveness of the 17 strategies are shown in Figure 8 (see page 19). Taken together, they can account for a reduction of some 70% in the microplastics problem by 2050, compared to the MAX scenario.

Category	Mitigation strategy	Explanation
Policy and regulations	**MS1**	Ban on deliberate microplastics
	MS2	Restriction of Single-Use Plastics
Waste management infrastructure	**MS3**	Upgrade water purification system
Behaviour	**MS4**	Wider rollout of deposit system
Cleaning and tidying up	**MS5**	Litter clean-up in roadsides, parks, woodland
	MS6	'Ocean clean-up'
	MS7	Extraction of plastics from landfills
Choice of materials	**MS8**	Materials/grades with improved MPI
Product design	**MS9**	Improved packaging concepts
	MS10	Improved car tyres (reduced abrasion)
Recycling process	**MS11**	Precision recycling technology
Separation technology	**MS12**	Implementation of washing machine filters
	MS13	Utilisation of improved air filters
	MS14	Recovery of agricultural foil
	MS15	Collection of rubber from roadsides and sports fields
	MS16	Car tyre recovery system
R strategies	**MS17**	R strategies: refuse and reduce

Table 1. Nine different categories of microplastics mitigation, including a brief description of the 17 strategies. These are explained below.

Mitigation strategies

Broad rollout of deposit principle results in much less litter

Policy and regulations

In 2019, the ECHA (European Chemicals Agency) submitted a proposal[26] for reducing the deliberate addition of microplastics to products. This mainly concerns cosmetics, with the aim being to reduce exposure and emissions of primary microplastics into the environment. Furthermore, new European rules on Single-Use Plastics (SUPS, i.e. disposable plastic items) have been in force since 2021. For example, certain products have been banned, such as plastic cutlery and drinking straws. In the Netherlands, the deposit system has been extended to small bottles, and guidelines for mandatory use of recycled plastics have been included (from 2025). Similar rules for SUPs have been introduced in a number of countries worldwide, with varying degrees of success (33-96%[27]).

MS1
Imposition of EU restrictions on primary microplastics in cosmetics. **Complete ban on use.**

MS2
Imposition of various restrictions on the use of Single-Use Plastics. **20% reduction in packaging plastics.**

Waste management infrastructure

In the Netherlands, there is an effective waste management system; this involves a combination of policies and regulations and is financed by industry (Extended Producer Responsibility schemes) and members of the public (waste disposal levies). As a result, only a small percentage of plastic waste is still dumped in landfills, with the majority being incinerated (with energy recovery) and a significant proportion (~30%) being recycled. For the Netherlands, the benefit lies not so much in improved waste management but in facilities for wastewater treatment. For some considerable time now, the presence of heavy metals in sewage sludge has largely led to a ban on using the latter as fertiliser; it must be incinerated[28]. This has the additional advantage that the microplastics in sludge from wastewater treatment plants do not end up on land but are destroyed. Microplastics do still remain in the water, however, and then find their way into surface water and eventually into the sea. It is therefore important to develop innovative concepts that further reduce the concentration of microplastics in wastewater. One example is the 'Wasser 3.0' company, which traps microplastics in an environmentally friendly manner by agglomerating them prior to treatment[29].

MS3
Upgrade facilities for removal of microplastics from wastewater by implementing innovative concepts. **90% reduction of microplastics in treated sewage water.**

Behaviour

Despite all the measures and infrastructure, the Netherlands still generates a significant quantity of litter. On an annual basis, this amounts to some 15 kilotonnes, equivalent to over 1,300 sea containers filled with plastic waste. This is mainly due to the improper use of single-use items. Banning Single-Use Plastics is only a partial solution to this problem. On the other hand, paying a deposit acts as an incentive for people to contribute actively to reducing litter. The recent introduction of deposits for small plastic bottles almost immediately led to a reduction of as much as 70% of such bottles in litter.[30] With the advent of smart digital markers, it will become technically easier to roll out the deposit principle more widely for products that currently still find their way into litter, such as PET trays or confectionary packaging.

MS4
Rollout of deposit system for plastic (food) packaging. **95% reduction in litter possible if the deposit amount is high enough.**

Mitigation strategies

Worldwide, plastic waste in landfills exceeds the amount in oceans

An alternative to deposit charges is the local collection of plastic in return for a small fee per weight, in the same way as children, schools, or sports clubs used to collect waste paper. In addition to encouraging desirable behaviour through rewards such as deposits, education can play a major role in teaching people how to handle single-use plastics properly. Furthermore, public authorities and companies can encourage this by setting a good example themselves. Sustainable procurement policies, for example, will allow authorities to select products that generate fewer microplastics (see 'Product Design'). Some retailers, for instance, encourage their customers to bring their own containers to be filled with certain products. Such initiatives result in less packaging waste and reduce the likelihood of litter. The latter approach falls under R strategy R1 'refuse and rethink' and is included in MS17 (implementation of R strategies R1 and R2).

Cleaning and tidying up

Public authorities, businesses, private individuals, and NGOs are active in launching and supporting all kinds of initiatives for cleaning up litter. For instance, companies can join 'Operation Cleansweep', which assists them in avoiding emissions of plastic pellets ('nurdles') into the environment. The Plastic Soup Foundation organises World Cleanup Day. In the Netherlands, NLSchoon [NLClean] encourages schools, clubs, companies, and municipalities to combine days out with clean-up activities. There are local initiatives such as Schone Helden [Cleaning Heroes], and more and more one sees the local communities picking up plastic litter in parks or woods and putting it in the designated container. If this trend continues, the volume of Dutch litter can be reduced significantly.

MS5
Encourage clean-up of litter in roadsides, parks, woodland; on top of extension of deposit system (MS4). **90% reduction in amount of litter that remains.**

Cleaning up urban areas is also possible in other countries, but in countries with lower prosperity the focus is more likely to be on cleaning up the plastic soup or emptying landfills. Well-known advocates of this include Boyan Slat and Merijn Tinga. Various technological solutions are being discussed, such as trawling[31], bubble curtains[32], or filtering the ballast water in sea-going vessels[33].

MS6
Implementation of various clean-up concepts. **90% removal of (floating) plastics along coastlines and beaches, and in rivers and oceans.**

The quantity of plastic waste dumped in landfills worldwide is many times greater than what is floating around in seas and oceans. In developing countries, valuable plastics such as PET and HDPE are already collected by the informal sector and sold to recycling companies, but most of the plastics are left behind. Initiatives are now in the scaling-up phase in which the plastic material is incorporated into new products, such as bricks[34] or asphalt[35]. When it comes to processing plastics from seas, oceans and landfills, chemical recycling or incineration would seem most appropriate, given the massive degradation of plastics in such environmental compartments. Although little plastic waste is still dumped in landfills in the Netherlands, this measure may still be effective for plastics dumped in the past.

MS7
Extraction of plastics from sanitary landfills followed by incineration. **90% efficiency, given the deterioration in the quality of plastics and the difficulties this causes in removing disintegrating plastics.**

Mitigation strategies

MicroPlastics Index (MPI) and average particle size calculated for 15 polymers

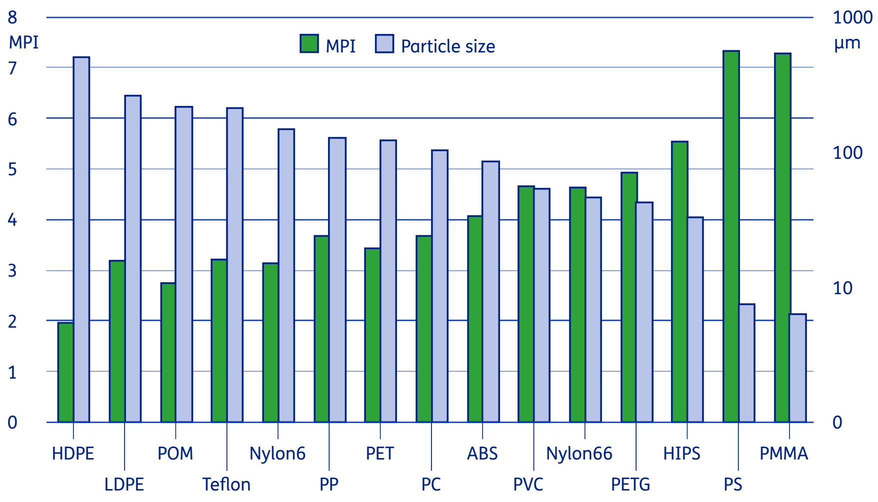


Figure 6. Calculated MicroPlastics Index (MPI, green) and particle size (blue) of virgin polymers. Source: TNO.

Choice of materials for textiles and packaging

Secondary microplastics result from degradation. The extent to which this takes place depends on the mechanical properties of the polymer. TNO has developed a special model for this. By combining material parameters on the strength, stiffness, and impact of a given type of polymer, it can calculate how many particles are formed and of what size[36]. We express this in the MicroPlastics Index (MPI). Figure 6 shows the MPI (blue, left-hand y-axis) for the most commonly used polymers. A low MPI (0-3, on a logarithmic scale) indicates that a polymer is tough and only a few, relatively large (> 200 micrometres) particles are formed. A high MPI (> 5) indicates that these plastics can form many small particles. Figure 6 shows that the choice of materials is of great importance in mitigating microplastics.
This involves more than just the type of polymer, such as PET, PP, or PE. Specific 'grades' of the polymer (PET for bottles, containers, or textile fibres) are also important. These grades are optimised by means of the process or with additives for the desired properties and applications. As a result, they may have a different MPI, with one grade resulting in more microplastics than another. Fibre PET, example, has shorter polymer chains than bottle PET, meaning the particle size of the microplastics can be as much as 10 times smaller. When the recycling process breaks down the PET chains even further, a material can be created that can be used for textiles but that has actually been degraded to such an extent that numerous microplastics are released during use[37].

We can therefore reduce the formation of microplastics from textiles and packaging by using a polymer type with a lower MPI that otherwise gives the product the same properties. This should then be in balance with the effect that the choice of a different material/grade could potentially have on the production process (for example processing at a slightly higher temperature).

MS8

Use of materials/grades with lower MPI for textiles and packaging. **90% reduction of MP formation throughout the entire life phase: production, use, end of life cycle.**

Mitigation strategies

Improving products in the design stage is essential to effectively reduce release of microplastics during use

In theory, biodegradable plastic packaging also offers an efficient mitigation strategy. Indeed, during the short usage phase, the packaging remains intact, after which the plastics are rapidly digested by micro-organisms. This is unlike non-biodegradable packaging that remains more or less intact for decades or even hundreds of years[38]. In practice, biodegradable plastics often turn out to be composed of a mixture of polymers, with some degrading relatively quickly while the rest are actually non-biodegradable[39]. Using such products will also lead to microplastics, perhaps even faster than in the case of 'normal' plastics, so there is no environmental benefit here. In the ideal case that a biodegradable polymer can in fact be developed that is usable for all packaging and actually decomposes in all environmental compartments, the impact is comparable to the STOP scenario for packaging in Figure 5, i.e. a maximum reduction of 25%. It is important, however, to select product groups that do not lead to more plastics being thrown away. Since we already know the extent of the impact due to the STOP scenario, we did not calculate a separate mitigation strategy for biodegradable plastics.

Product design for packaging and car tyres

The properties of the polymer affect the formation of microplastics, but we can also look at the formulation and design of products. It has been shown, for example, that microplastics can be released during such simple actions as opening a plastic bottle, tearing open packaging, or unrolling adhesive tape[40]. By enhancing safe-by-design principles with specific requirements, we can design packaging to release fewer microplastics during use. We can also reintroduce pouring spouts instead of caps, replace adhesive layers with closure strips, and so on.

MS9

Selection of suitable materials and application of relevant safe-by-design principles for packaging. **80% reduction of MP formation throughout the production and usage phase.**

Incorporating or omitting additives in the formula for a plastic product can reduce the formation of microplastics during the usage phase and at the end of the product's life cycle. Research is currently under way[41], for example, to improve the formula of car tyres so that they wear less without compromising performance. It's important to take into account the increasing use of heavier electric cars in this regard. Should this development succeed, it could greatly reduce the quantity of microplastics released annually from tyres (see Figure 3).

MS10

Use of new tyres with reduced abrasion. **80% reduction of MP formation throughout the entire life cycle.**

It should be noted that keeping car tyres properly inflated also reduces abrasion[42].

Process design for recycling

Recycling aims and guidelines require additional attention. Currently, even the most advanced countries mainly carry out plastic downcycling, for example using plastic waste as raw material for sheet piling, roadside bollards, and the like. For food safety reasons, using recycled packaging as food packaging has been made legally almost impossible. Improvements in supply chain management and the quality of recyclates can do away with these obstacles so that the recycling percentage increases.

The Microplastics Index can be incorporated into product design to reduce environmental impact

Recycling plastics can have a major impact on the formation of microplastics, however. Firstly, the plastic is subjected to mechanical stress during all the processing steps (sorting, shredding, washing, extrusion), which can lead to wear and tear, breakage, or stretching.

Mitigation strategies

In the course of the recycling process, this can create microplastics, which are released during the washing or drying steps. Secondly, most recycling processes cause a deterioration in the properties of the plastics[43], which increases the MPI and allows more particles to be formed during the next production-use-recycling cycle.

In a fully circular approach, this loop (cycle) is ideally repeated several times without a negative impact on the MPI. Little is yet known, however, about the impact of this on increasing the risk of microplastics formation. TNO therefore experimentally investigated a worst-case scenario[44]. Polypropylene (PP) was recycled five times (extrusion-chopping-injection moulding-shredding-washing-drying) without re-stabilising the polymer for each cycle (by adding additives). During each cycle, any material lost was trapped and analysed. Mechanical properties of the plastic were also measured as input for the MPI. Figure 7 shows that the MPI (right-hand y-axis) increased with each subsequent run (x-axis). This indicates that more (and smaller) microplastics were formed in each subsequent step. This was confirmed by the experimentally measured mass of recycled plastic and particles trapped during the run (left-hand y-axis). Recycling multiple times therefore means that material losses, in the form of microplastics, increase with each cycle.

It is therefore very important to design recycling processes in such a way as to safeguard the quality of plastics more effectively, so that a smaller quantity of microplastics can be released. TNO is participating in a recently launched project aimed at reducing such material losses during recycling[45]. One example of the advanced process technology needed is a shredder that uses just enough energy to reduce the size of plastic products without the surplus resulting in the formation of microplastics.

MS11

Implementing yet-to-be-developed precision process technology. **90% reduction of MP formation during recycling.**

Multiple-loop recycling experiment TNO

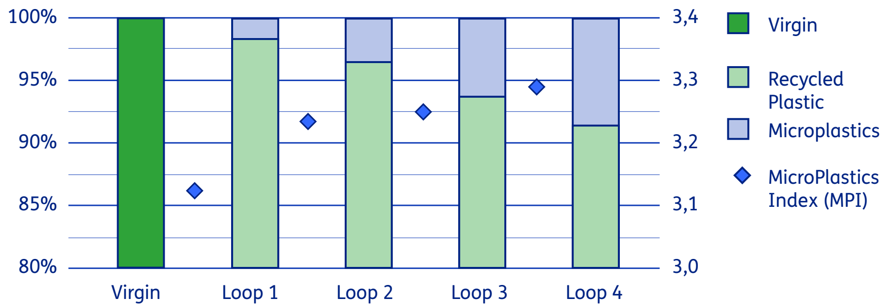


Figure 7. MicroPlastics Index ◆ and mass balance (column) of TNO multiple-loop experiment with polypropylene. Source: TNO.

Separation technology for microplastics from packaging, car tyres, agricultural foil, and textiles

When emissions of microplastics cannot be prevented, we must ensure that they cause as little harm as possible to humans and the environment. In short, we need to trap these microplastics as close to the source as possible (source separation). Here too, various relevant initiatives are worth reviewing. For example, filters for washing machines are currently being developed to ensure that textile fibres no longer end up in the sewers[46]. Despite the presence of advanced wastewater treatment plants, a limited proportion of these fibres still disappear downstream towards the seas and oceans, certainly in the case of less developed countries.

MS12

Use of special microplastics filters for washing machines. **80% reduction in emissions of microplastics from textiles into wastewater.**

Mitigation strategies

In the same category are filters that purify indoor air using mechanical and electrostatic filtration. These systems can form part of a mechanical ventilation system or operate as a standalone. Currently, particles as small as 0.1 mm can be removed with 99% efficiency.[47] Further development of this technology will enable removal of even smaller microplastic particles, including also a direct effect on particles (<10 micrometres) relevant to our lungs.

MS13

Use of indoor air filters. **90% reduction in emissions to lungs.**

In the agricultural sector, plastic foils are largely disposed of after use, but torn-off pieces are regularly ploughed into the ground, significantly contributing to the problem (see Figure 4). Technology (yet to be developed) and due care, combined with materials with a lower MPI, can largely overcome this problem. Biodegradation can play a positive role here if the right materials and concepts are applied.

MS14

Implementation of improved technology and use of materials/grades with a lower MPI. **90% reduction in plastic foil ploughed into the fields and 90% reduction in MP formation.**

If it turns out not to be technically feasible to develop tyres with less abrasion (MS10), alternatives will be needed for this major source of microplastics. In the Netherlands, pervious concrete/asphalt (‘ZOAB’) has been used to surface motorways for decades. 95% of the microplastics formed are trapped in the porous structure of this product[48]. It is regularly cleaned, after which the wastewater, including the microplastics, is treated. This is an effective way of reducing emissions into the environment. Since ZOAB is only used on motorways, this solves roughly half the problem, with the other half of the microplastics still ending up on the verges alongside the road. Further development and introduction of systems[49] to remove microplastics from the run-off water would be very welcome. Such systems can also be used to reduce emissions into surface water from artificial-turf sports fields that have been infilled by being strewn with (recycled) rubber granules.

MS15

Development and introduction of a run-off water treatment system for roads and sports fields to reduce the release of microplastics into the environment. **90% reduction of emissions by purification system.**

A recent innovation involves trapping rubber microplastics at the tyres themselves[50]. A prototype is capable of trapping about 60% of the particles. This is comparable to using ZOAB, but probably a lot less pricey. The car of the future ought to have such a trapping system, combined with tyres that wear less (MS10).

MS16

Creation of a rubber particle trapping system for cars, together with the MS10 improved tyres. **96% reduction of MP emissions.**

R strategies: refuse (R1) and reduce (R2)

In addition to these measures, a number of countries are introducing various R strategies: refuse and rethink (R1), reduce (R2), reuse (R3), repair (R4), recycle (R5), and recover (R6). In the Netherlands, more and more supermarkets are selling packaging-free products[51]. The widespread rollout of such concepts would significantly reduce plastic consumption, resulting in less microplastics formation and exposure.

MS17

Implementation of R strategies R1 and R2, **resulting in an annual decrease of 1% by 2050** (versus the MAX scenario of 4% annual growth).

How effective are all these options?

For an explanation of the 17 mitigation strategies and their division into the 9 corresponding categories see table 1 on page 12.

Effectiveness
The effectiveness of each of the 17 mitigation strategies (see Table 1 for the overview) was calculated using the TNO model. The results are summarised in Figure 8.

Effectiveness is defined here as the ability to prevent the current formation of microplastics (primary and secondary) and future formation (secondary, from plastic waste already present in the environment).

The MAX scenario (2050, see Figure 5 page 10) was taken as the reference point.

Effectivity of mitigation strategies

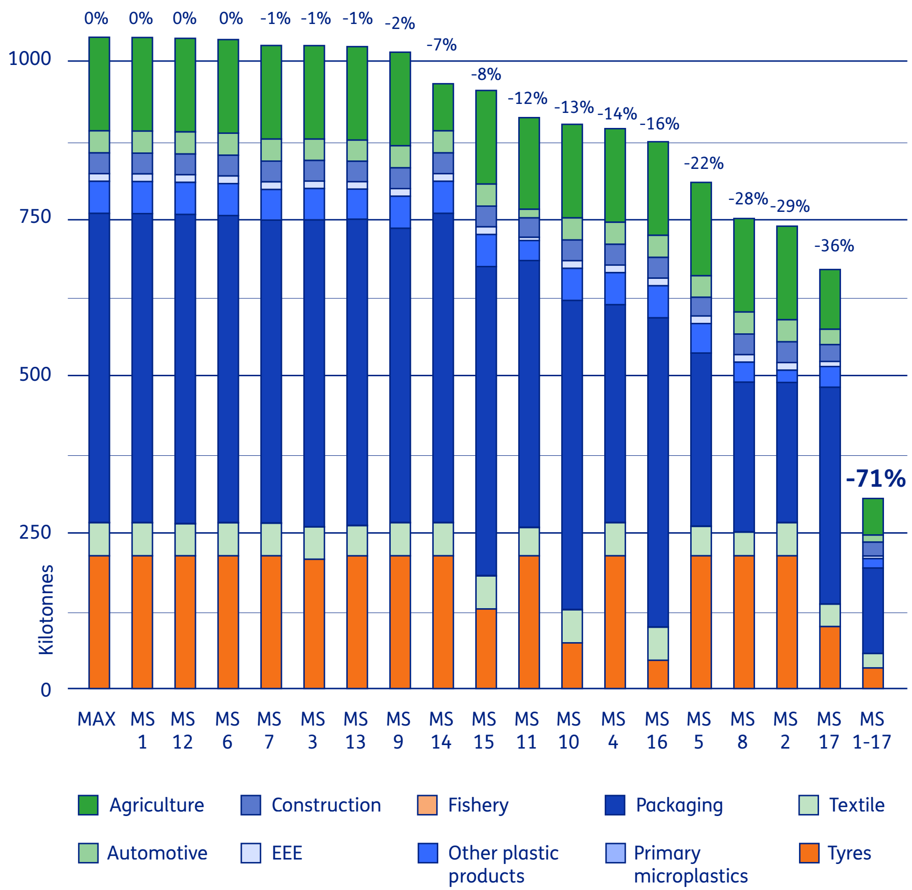


Figure 8. Effectiveness of all individual measures relative to the MAX scenario (left-hand column) for the Netherlands. The right-hand column (MS1-17) gives the effectiveness of the combination of these mitigation strategies. Source: TNO.

Impact
Figure 8 shows that there are five mitigation strategies that can have a significant impact (>15%) as regards preventing or reducing the formation of microplastics:

MS17
Introduction of R strategies R1 and R2;

MS2
Restriction of Single-Use Plastics;

MS8
Use of improved materials
(with lower MPI);

MS5
Extension of deposit system (MS4) combined with clean-up of litter;

MS16
Use of improved car tyres (MS10) together with trapping of rubber particles.

Compartments with leftover microplastics

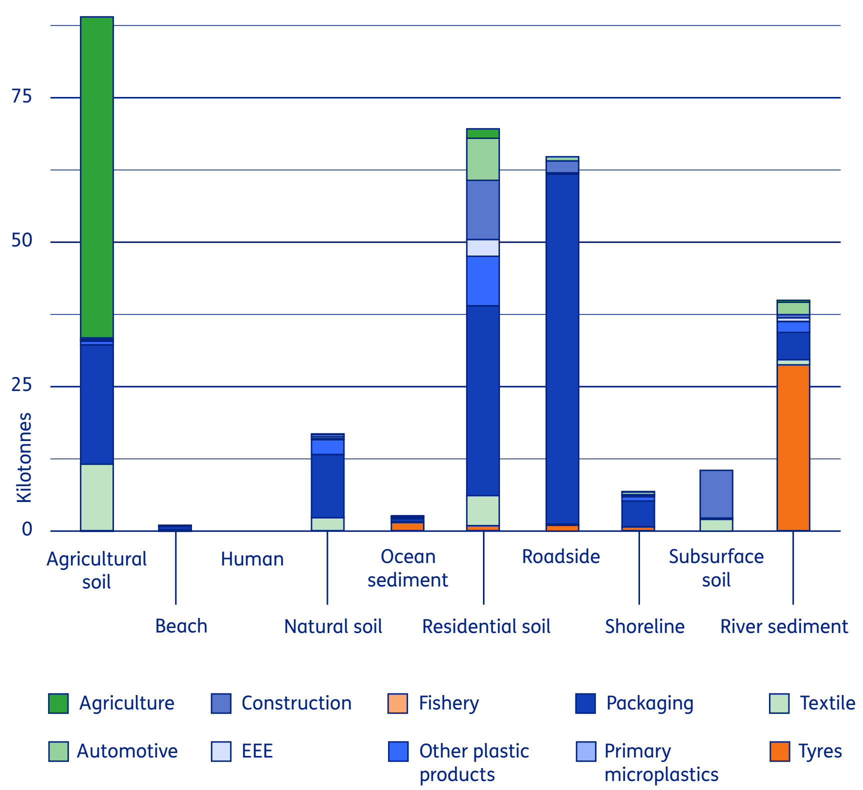


Figure 9. Microplastics that are still present in various environmental compartments in 2050 after implementation of the 17 mitigation strategies. Source: TNO.

Preventing litter is just as important as cleaning up plastics already present

However, there are also seven measures that have little or no effect: 98-100% of the problem persists after the relevant mitigation strategy has been implemented. Figure 8 makes clear that a combination of measures will be needed to solve the problem of microplastics satisfactorily. But not all the solutions can be combined with one another. It makes no sense, for instance, to select a different material for plastic straws if they are banned anyway. This was factored into the calculation of MS1-17, which shows that combining all mutually compatible mitigation strategies could result in human and environmental exposure to microplastics decreasing by around 70% by 2050 (compared to the MAX scenario). Implementing these mitigation strategies will already bring about a 37% reduction by 2030, in line with Dutch and European aims (a 30% reduction by 2030)[52].

Cleaning up and preventing litter

The roughly 30% of microplastics remaining after implementing the 17 measures will be present throughout the environment in compartments that are difficult to clean up (see Figure 9). A river bed that is strewn with microplastics (a 'river sediment') is a good example of a difficult compartment to clean up. Moreover, most of the remaining microplastics are formed from plastics that degrade in the environment. Preventing litter is thus an important task, but cleaning up plastics already present is just as important. This is no easy matter, however, because they are often buried, and so remain out of sight during clean-up and tidying campaigns.

Figure 9 indicates that some mitigation strategies require an additional effort to achieve a greater reduction in microplastics exposure.

Not calculated

The following options were not calculated using the model:

- Agricultural foil recovery (MS14): from 90 to 95% or use of biodegradable materials;
- Growing awareness of the consequences of 'throw-it-away' behaviour, resulting in less plastic pollution;
- Deposit system (MS4): from 95 to 99% effective through targeted measures aimed at packaging frequently found in litter;
- Improved filters and trapping systems that further reduce emissions of microplastics into surface water (MS15).

People, microplastics, and mitigations

TNO's Microplastics Model allows us to group information specifically with regards to human exposure to microplastics.

Broadly speaking, we can be exposed to microplastics in three ways: through inhalation, digestion, and the skin.

The scientific literature indicates that inhalation and digestion are particularly important[53]. Effective mitigation methods therefore focus specifically on improving air quality on the one hand and food quality on the other. Air quality will improve as an indirect consequence of implementing a wide range of mitigation strategies (10, 16, and 17), while individuals can improve air quality by utilising effective air filters (MS13). The presence of plastic litter (MS2, 5) in various environmental compartments will have an indirect effect on the quality of our food system. Improving plastic packaging (MS9) has a direct effect. By combining new products, technology, behaviour and regulations, a reduction of some 55% is possible compared to the MAX scenario.

The model shows that abrasion of car tyres is the greatest source of microplastics (~35%), followed by packaging (~25%).

The remaining 40% is miscellaneous: textiles, other plastic products, and automotive plastics (excluding rubber).

What prospects are there for action?

Developing and implementing this package of effective mitigations requires cooperation throughout the value chain between public authorities, industry, and consumers

International context
The globalisation of food and value chains means that the parties that need to take action are not only to be found in the Netherlands. Therefore, we indicate in the following description of the action plan where we are dependent on European and international developments in the areas of technology, behaviour and legislation.

MS17
MS17 (R strategies) necessitates a societal change regarding the use of plastics, particularly packaging. This requires NGOs, consumers, and the retail sector to sit down together to come up with new formulas that will lead to a reduction in the (growth of) consumption of plastics. EU legislation can create the right (market) conditions for this.

MS8, MS10, MS14 and MS16
For MS8, MS10, MS14, and MS16 (materials selection and product design), the rubber and plastics industries are working with research institutes to develop new materials and formulations that result in packaging and tyres with significantly less microplastics formation throughout their life cycle. Cooperation with leading European and international parties can accelerate these developments. The government can provide the appropriate legal framework, for instance by tightening up safe-by-design principles with regard to the formation of microplastics. Furthermore, 'the voice of the customer' can drive demand for new and improved products. Attention is also needed for biodegradable polymers as mitigation for microplastics formed from litter that still, despite everything, ends up in the environment.

MS2, MS4 and MS5
In the case of MS2 (legislation) and MS4 (deposit systems), national and also EU governments have a major role to play. When rolling out new policy and legal frameworks, transparency is important, but steadfastness is also needed so that exceptions are not piled on top of exceptions. Informing consumers about the 'why' and engaging them is also important here. Government policy-makers and end-users need to cooperate at an early stage.
In the case of MS5 (litter clean-up) specifically, digitalisation, such as digital marking, is necessary for a wider rollout than just bottles alone. The technology suppliers that are working on this development therefore also play a leading role.

MS11 and MS15
For MS15 (separation of rubber at the source), the Directorate-General of Public Works and Water Management [Rijkswaterstaat] in particular will need to take action to determine the best way to trap the diffuse emissions of microplastics. Where necessary, the development of robust technology will be needed. Something similar applies to MS11 (recycling technology): current actors in the sector are tasked with improving recycling technologies.

What will this action plan cost?
And what are the right priorities?

Without public support for the cost of this mitigation package, the aforementioned stakeholders will not become active.

Table 2 shows a qualitative estimate of the costs for each mitigation strategy, based on expert opinion and stakeholder inter-views.

Together with the potential effectiveness of the mitigations (Figure 8 page 19) and the speed with which these measures can be developed and implemented (expert opinion), this (consolidated) qualitative estimate of the costs of the action plan provides an initial understanding of the assessment framework for the Netherlands (Figure 10 page 24).

Mitigation strategy		Costs/benefits for public	Costs/benefits for industry	Effect on CO2/ climate	Consolidated input Figure 10
MS2	SUP restrictions	0	-	?	-/0
MS3	Wastewater treatment	-	-	+	-
MS4	Deposit charges	0	+	+	+
MS5	Cleaning up verges, woodland, parks	0	0	+	0
MS7	Cleaning up landfills	0	0/+	+	0/+
MS8	Improved materials	+	+	+	+
MS9	Improved packaging	0	-	+	0
MS10	Improved car tyres	+	+	+	+
MS11	Improved recycling	0	++	+	++
MS13	Air filters	-	0/+	0	-
MS14	Recovery of agricultural foil	0	0	0	0
MS15	Roads and sports field collection	--	0	+	--
MS16	Car tyre recovery system	-	0	0	-
MS17	R strategies refuse & reduce	+	-	?	0

Table 2. Qualitative estimate of costs (-)/benefits (+) per mitigation strategy (strategies with minimal impact omitted). Costs that lie with government are here categorised under public, given that it is the public who bear these costs indirectly through taxation. Source: TNO.

Priorities

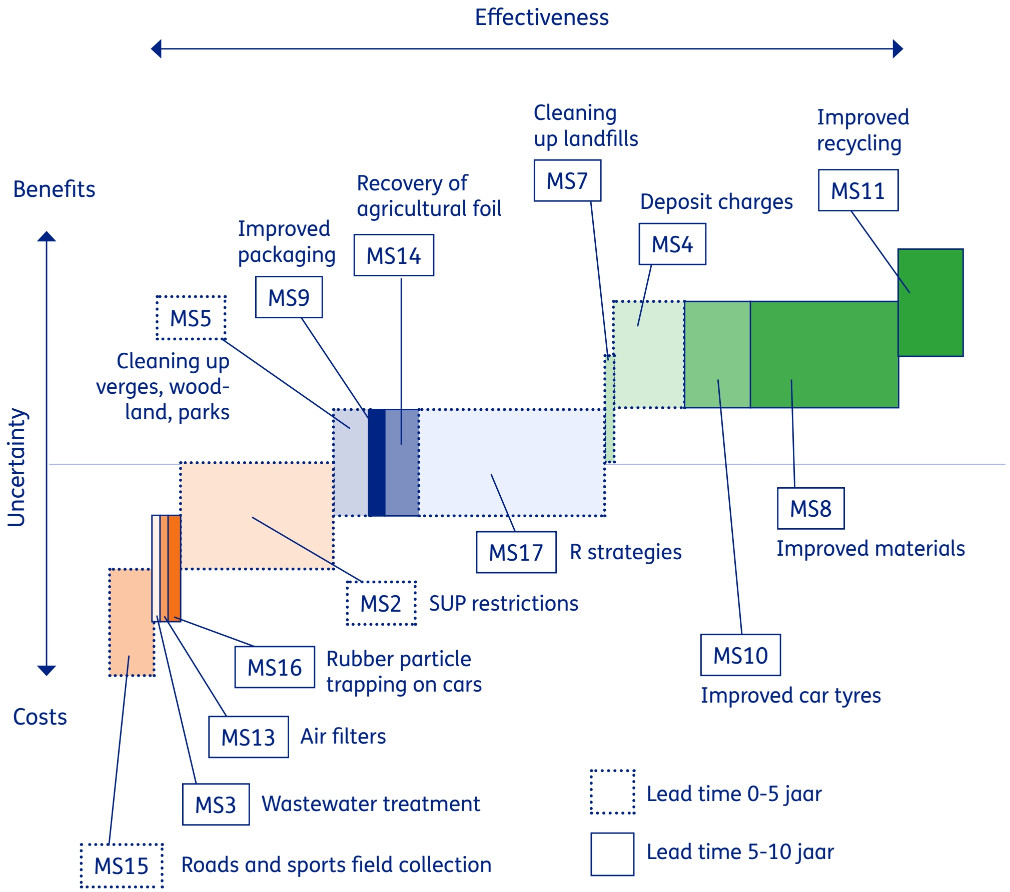


Figure 10. Costs (or benefits) versus effectiveness per mitigation strategy. The width of the bar corresponds to degree of effectiveness (from Figure 8), while the height of the bar suggests the uncertainty of the costs estimate. Dotted line areas indicate a lead time of 0-5 years to implement the relevant mitigation strategy; solid line areas have a lead time of 5-10 years. Source: TNO.

Figure 10 shows the costs/benefits (y-axis) of a mitigation strategy as a function of its degree of effectiveness (x-axis). This shows at a glance which measures are both effective (wide bar) and cost-effective (above the x-axis). For such mitigation strategies, public support is easier to achieve than for measures that directly affect the consumer's wallet. Figure 10 also shows which measures can be introduced in the short term (unshaded areas) and which in the longer term (shaded areas).
The action plan described above requires national coordination by the Dutch government. The assessment framework shown in Figure 10 can help government policy-makers to set the right priorities together with the various stakeholders.

Priorities listed:

MS4 – Deposit systems
Further rollout of deposit systems (MS4), especially for those (packaging) products that currently often end up in the environment as litter. The necessary technology, such as digital marking, can be available within a five-year period. Government can encourage this.

MS17 – R strategies
Focus on accelerating the development and implementation of R strategies (MS17), where necessary with EU and international stakeholders.

MS5 – Cleaning up verges, woodland, parks
Support and encouragement for local initiatives that reduce litter along roads, in parks, and in conservation areas (MS5).

MS11 – Improved recycling technologies
Accelerate research into/introduction of improved recycling technologies. The Netherlands is home to a number of top (scientific) institutes that, with the right focus and resources, can make progress on successfully developing MS11.

MS8, MS10 en MS14 – Innovative materials
Cooperation with EU and international organisations to deliver innovative materials for reducing the degradation of packaging (MS8), tyres (MS10), foils (MS14), and textiles (MS8), including the use of biodegradable materials.

MS2 – SUP restrictions
Impose (implementation and compliance) effective EU and international legislation on SUPs (MS2), including an assessment of the sustainability of any alternatives adopted.

MS15 – Roads and sports field collection
Development of technology, associated policy frameworks, and business models for mitigation of non-point sources of microplastics (rubber (MS15), paints/coatings).

An appealing perspective

If successfully implemented, this action plan will make our woodland, roadsides, rivers, seas, and oceans clean again.

Exposure to the potentially harmful effects of microplastics will then be significantly reduced and we will have fresh outdoor air, clean drinking water, and safe food.

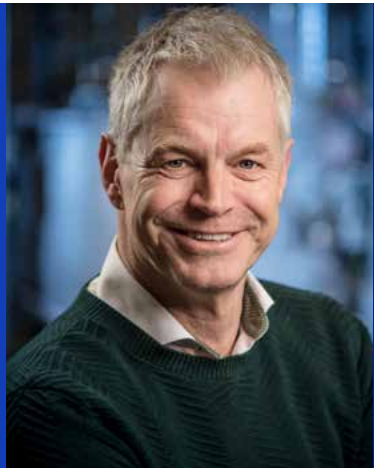
Companies in the plastics value chain will keep their licence to operate and shape the transition towards circular plastics.

References

Abbreviations
HDPE = high density polyethylene, LDPE = low density polyethylene, PP = polypropylene, PS = polystyrene, E-PS = expanded-polystyrene, PVC = polyvinyl chloride, PET = polyethylene terephthalate, ZOAB = porous asphalt

1 TNO publicatie “Verspil het niet!” uit 2020: | https://www.tno.nl/en/focus-areas/circular-economy-environment/roadmaps/circular-economy/plastics/
2 Towards a definition of microplastics (rivm.nl) | https://www.rivm.nl/bibliotheek/rapporten/2015-0116.pdf
3 Detection of microplastics in human lung tissue using μFTIR spectroscopy | https://doi.org/10.1016/j.scitotenv.2022.154907
4 Discovery and quantification of plastic particle pollution in human blood | https://doi.org/10.1016/j.envint.2022.107199
5 Evidence on microplastics does not yet point to widespread risk, say Europe’s top scientists – SAPEA | https://sapea.info/microplastics-launch/
6 Dietary and inhalation exposure to nano- and microplastic particles and potential implications for human health (who.int) | https://www.who.int/publications/i/item/9789240054608
7 A/CONF.151/26/Vol.I: Rio Declaration on Environment and Development (un.org) | https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf
8 Belanghebbenden bij het voorzorgsprincipe | Rathenau Instituut | https://www.rathenau.nl/nl/kennisgedreven-democratie/belanghebbenden-bij-het-voorzorgsprincipe
9 World Economic Forum: The New Plastics Economy | https://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf
10 EU plastics strategy | https://www.europarc.org/wp-content/uploads/2018/01/Eu-plastics-strategy-brochure.pdf
11 EU Circular Economy Action Plan | https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN
12 ECHA proposes to restrict intentionally added microplastics | https://echa.europa.eu/-/echa-proposes-to-restrict-intentionally-added-microplastics
13 Response from the Netherlands to the European Commission’s public survey on Microplastics pollution – measures to reduce impacts on the environment | Rapport | Rijksoverheid.nl | https://www.rijksoverheid.nl/documenten/rapporten/2022/06/09/bijlage-2-pc-microplastics-additional-response-from-the-netherlands-to-the-public-survey-on-microplastics
14 TNO paper “Plastics in the global environment assessed through material flow analysis, degradation and environmental transportation”, submitted to Science of The Total Environment
15 Degradation Rates of Plastics in the Environment | ACS Sustainable Chemistry & Engineering | https://doi.org/10.1021/acssuschemeng.9b06635
16 Knowledge hub • Plastics Europe | https://plasticseurope.org/knowledge-hub/
17 What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 | Urban Development (worldbank.org) | https://elibrary.worldbank.org/doi/abs/10.1596/978-1-4648-1329-0
18 EUROMAP - Market Data | https://www.euromap.org/markets/market-data
19 Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment | https://doi.org/10.3390/ijerph14101265
20 Environmental Degradation of Tire-Wear Particles | Rubber Chemistry and Technology | https://doi.org/10.5254/1.3535066
21 Tyre and road wear particles (TRWP) - A review of generation, properties, emissions, human health risk, ecotoxicity, and fate in the environment | https://doi.org/10.1016/j.scitotenv.2020.137823
22 Aging of tire and road wear particles in terrestrial and freshwater environments – A review on processes, testing, analysis and impact | https://doi.org/10.1016/j.chemosphere.2021.132467
23 World Economic Forum: The New Plastics Economy | https://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf
24 https://www.tno.nl/en/focus-areas/circular-economy-environment/roadmaps/circular-economy/plastics/
25 EU plastics strategy | https://www.europarc.org/wp-content/uploads/2018/01/Eu-plastics-strategy-brochure.pdf
26 Registry of restriction intentions until outcome - ECHA (europa.eu) | https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18244cd73
27 Governance Strategies for Mitigating Microplastic Pollution in the Marine Environment: A Review | https://doi.org/10.3390/microplastics1010003
28 Afzet van zuiveringsslib naar bestemming, 1981-2020 | Compendium voor de Leefomgeving (clo.nl) | https://www.clo.nl/indicatoren/nl0154-afzet-van-zuiveringsslib-naar-bestemming
29 Technology - Wasser 3.0 (wasserdreinull.de) | https://wasserdreinull.de/en/our-offers/technology/
30 Zwerfinator ziet sterke afname plastic flesjes in zwerfafval - ZWERFINATOR | https://zwerfinator.nl/zwerfinator-ziet-sterke-afname-plastic-flesjes-in-zwerfafval/
31 The Ocean Cleanup | https://theoceancleanup.com/
32 The Great Bubble Barrier - A smart solution to plastic pollution | https://thegreatbubblebarrier.com/
33 A simple technique to mitigate microplastic pollution and its mobility (via ballast water) in the global ocean | https://doi.org/10.1016/j.envpol.2021.117070
34 Kenyan recycles plastic waste into bricks stronger than concrete | Reuters | https://www.reuters.com/article/us-kenya-environment-recycling-idUSKBN2A211N
35 Recycling van plastics in asfalt – een analyse | https://brrc.be/sites/default/files/2020-10/SN50.pdf
36 MPI paper TNO: to be submitted
37 Do Recycled Cotton or Polyester Fibers Influence the Shedding Propensity of Fabrics during Laundering? | https://doi.org/10.14504/ajr.7.S1.4
38 Degradation Rates of Plastics in the Environment | ACS Sustainable Chemistry & Engineering | ACS Sustainable Chemistry & Engineering | https://doi.org/10.1021/acssuschemeng.9b06635
39 Microplastics generated from a biodegradable plastic in freshwater and seawater - ScienceDirect | https://doi.org/10.1016/j.watres.2021.117123
40 Microplastics generated when opening plastic packaging | Scientific Reports (nature.com) | https://doi.org/10.1038/s41598-020-61146-4
41 Leon-T Project – European Project (leont-project.eu) | https://www.leont-project.eu/
42 Potential measures against microplastic emissions to water (rivm.nl) | https://www.rivm.nl/bibliotheek/rapporten/2017-0193.pdf
43 Study of thermal and mechanical properties of virgin and recycled poly(ethylene terephthalate) before and after injection molding | https://doi.org/10.1016/S0014-3057(99)00301-8
44 TNO multiple-loop recycling paper, to be submitted.
45 LEMPLAR - Losses & Emissions in Plastic Recycling (ispt.eu) | https://ispt.eu/projects/lemplar/
46 PlanetCare houdt met wasmachinefilter plasticvervuiling tegen bij de bron - Duurzaam Ondernemen (duurzaam-ondernemen.nl) | https://www.duurzaam-ondernemen.nl/planetcare-houdt-met-wasmachinefilter-plasticvervuiling-tegen-bij-de-bron/
47 Blueair Air Purifiers Remove Microplastics From the Air (prnewswire.com) | https://www.prnewswire.com/in/news-releases/blueair-air-purifiers-remove-microplastics-from-the-air-684554861.html
48 Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment| https://doi.org/10.3390/ijerph14101265
49 Removal of rubber, bitumen and other microplastic particles from stormwater by a gross pollutant trap - bioretention treatment train | https://doi.org/10.1016/j.watres.2021.117457
50 World’s first device to capture harmful tyre particles invented by students | Imperial News | Imperial College London | https://www.imperial.ac.uk/news/195595/worlds-first-device-capture-harmful-tyre/
51 Verpakkingsvrij wordt steeds normaler: ‘Het is niet moeilijk, maar je moet er wel voor in actie komen’ - EenVandaag (avrotros.nl) | https://eenvandaag.avrotros.nl/item/verpakkingsvrij-wordt-steeds-normaler-het-is-niet-moeilijk-maar-je-moet-er-wel-voor-in-actie-komen/
52 Response from the Netherlands to the European Commission’s public survey on Microplastics pollution – measures to reduce impacts on the environment | Rapport | Rijksoverheid.nl | https://www.rijksoverheid.nl/documenten/rapporten/2022/06/09/bijlage-2-pc-microplastics-additional-response-from-the-netherlands-to-the-public-survey-on-microplastics
53 Microplastics in the Environment: Intake through the Food Web, Human Exposure and Toxicological Effects | https://www.mdpi.com/2305-6304/9/9/224

Authors
Jan Harm Urbanus
Andrea Brunner, Arjen Boersma,
Sieger Henke, Ingeborg Kooter,
Sietske Lensen, Luke Parker,
Anna Schwarz, Pieter Imhof,
Ardi Dortmans, Marinke Wijngaard



Contact
Pieter Imhof

Business developer
Circular economics and environment

pieter.imhof@tno.nl
+31 6 51 52 11 79
https://www.linkedin.com/in/pieterimhof/

TNO innovation for life

Circular Plastics
In order to avoid the exhaustion of natural resources and to positively contribute to climate change, reduction in plastic waste is of great importance. We make it possible for the plastics that we use to be circular. TNO develops scenario models to give direction to the transition to a circular economy. Together with our partners we are working towards improved products, new recycling technologies and research into (the effect of) microplastics.

tno.nl/microplastics-en