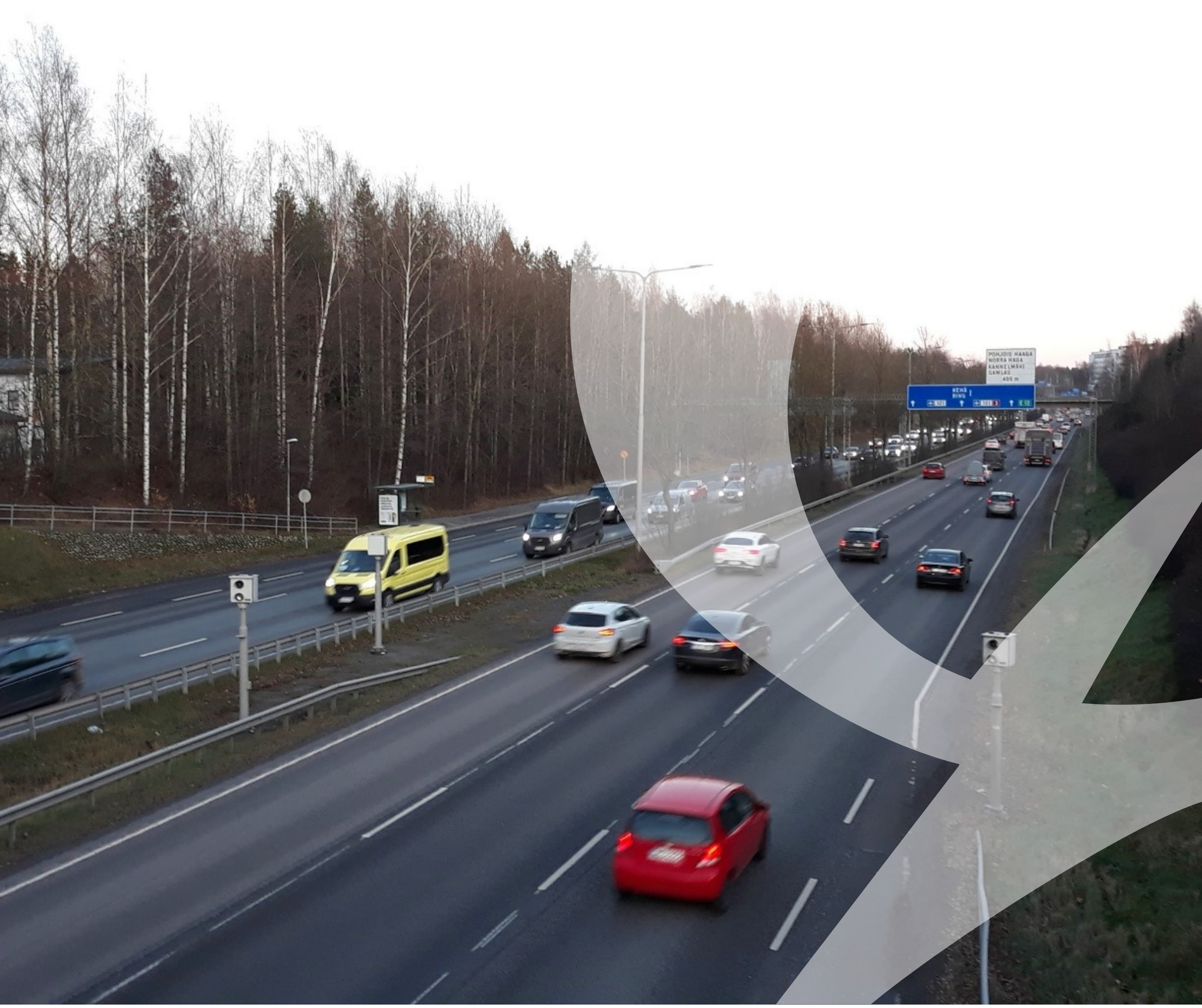

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Traffic microplastics – solutions to mitigate the problem

FanpLESStic-sea project report

Erika Winquist, Marjatta Vahvaselkä,
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Summary

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Traffic microplastics, i.e. tyre and road wear particles, are reported as the largest group of microplastics entering the environment and finally the sea. Thus, it is most critical to decrease the amount of especially traffic related microplastics and here already a small relative decrease can be significant.

The primary aim of the EU's 'Sustainable and Smart Mobility Strategy' is to reduce transport related GHG emissions by at least 90% by 2050 compared to 1990. However, a carbon neutral transportation system is not enough, also other traffic related contamination, such as tyre and road wear particles, should be considered. On the contrary, with increasing number of electric vehicles, even more attention should be paid to tyre wear. Electric cars can accelerate faster than many traditional cars, which may lead to increased tyre wear. In addition, electric cars are today generally heavier than cars that run on liquid fuels or gas, due to the weight of the batteries.

The most efficient way to reduce the amount of tyre and road wear particles in the environment are through preventive methods. Factors that affect tyre and road wear are related to proper use of tyres, driving behaviour, and the characteristics of the tyres as well as road surfaces. These are all presented in this report in more detail. A good starting point to tackle the traffic microplastics' problem is all kind of public awareness raising campaigns. Some improvements might also need supportive policies for their realization. However, there is already a lot what we can do even without further technical development. But for successful implementation, commitment is needed from all stakeholders; policy makers, industry, municipalities and consumers.

Keywords: microplastics, traffic, tyre wear particles, prevention

Contents

1. Introduction

Traffic microplastics, i.e. tyre and road wear particles, have been identified as a major source of microplastics in the environment in Europe as well as in Finland (Sundt et al. 2016, Hann et al. 2018, Setälä and Suikkanen 2020). Traffic microplastics particles originate mainly from tyre rubber, but also from road markings and sometimes from polymer modified bitumen, which is used in the asphalt (Andersson-Sköld et al. 2020). However, pure tyre wear particles exist in very low quantities in the environment, while most tyre wear particles are associated with road material (Grigoratos and Martini 2014). The pathways for traffic microplastics to end up in aquatic environments are through stormwater and air (Essel et al. 2015, Sundt et al. 2016, Kole et al. 2017).

Today, the knowledge on traffic microplastics is still surprisingly limited and thus, more attention should be paid to the topic covering the presence, pathways, effects, and risks of traffic related microplastics. Especially, research is needed about the effects on the environment and human health caused by the exposure of microplastics. Despite the lack of knowledge, the risks should be taken seriously based on the facts that 1) emissions from tyre and road wear are very high, 2) the particles are likely to be persistent in the environment, and 3) the particles contain hazardous substances as well as hazardous substances from the environment may be sorbed on the surface of the particles (Andersson-Sköld et al. 2020).

Cutting CO_2 emissions from traffic has been an everyday topic for more than a decade, but microplastic and other type of chemical pollution caused by traffic has received much less attention. Furthermore, in the battle against traffic CO_2 emissions, hybrid and pure electric cars are becoming more popular. As electric cars are heavier than conventional ones, this would mean they are expected to release even more tyre related microplastics to the environment.

There are some known ways to reduce microplastic emissions from traffic, the simplest one being to reduce traffic as identified in a Norwegian report on microplastic pollution and reduction potential (Sundt et al. 2016). However, reducing traffic would most likely work on a local level but on a country level the effect would be relatively small (Sundt et al. 2016). Moreover, the road traffic is expected to increase rather than decrease. On EU level, estimates suggest that passenger transport will increase by 42% by 2050, and freight transport by 60% (EC 2019). Other possible ways to reduce microplastic emissions from traffic include more durable tyres (in terms of tyre wear), driving behavior (eco-driving), optimizing road surfaces to wear less on tyres without compromising safety issues, improved sewers as well as road cleaning.

This report is an output of the FanpLESStic-sea – "Initiatives to remove microplastics before they enter the sea" (Jan 2019–Dec 2021) project, which is an EU INTERREG funded Baltic Sea Region project aimed at decreasing and removing microplastics in the Baltic Sea, through the delivery of the following outputs:

- A model to map, understand and visualize microplastic pathways that will be applied to the partners' cities and/or regions;
- Piloting of new technology: for filtering out microplastics; sustainable drainage solutions as means for removal of microplastics; and to remove microplastics from stormwater
- Defining innovative governance frameworks and engaging a large range of players for the implementation of coordinated and cost-efficient measures resulting in locally adapted investment proposals/plans for each partner's region; and

- Dissemination of project results, including reports on barriers and ways forward, to increase institutional capacity on up-stream and problem-targeted methods to remove microplastics.

More specifically, this report is concentrating on the Activity 3.1 State-of-the-art microplastic removal technologies of the FanpLESStic project lead by the Natural Resources Institute Finland (Luke) which aims to identify and validate state-of-the-art microplastic removal technologies and develop and refine new solutions.

The aim of this report is to offer a short overview on traffic microplastics, highlight the importance of the topic and offer some solutions to mitigate the problem and suggestions for further reading. The focus is on tyre wear particles as they were identified as the major source of secondary microplastics in a review on existing policies and research related to microplastics, also conducted as a part of the FanpLESStic-sea project (HELCOM; 2019). Moreover, the focus is on preventive methods as they are recognized the most efficient method to prevent the traffic microplastic pollution (Sundt et al. 2016).

The term *traffic microplastics* is used as a general term for all the road associated microplastics (tyre wear particles, road markings and polymer modified bitumen) and *tyre wear particles* referring to the microplastic emissions related to car tyres.

2. Background

2.1. Sources and pathways

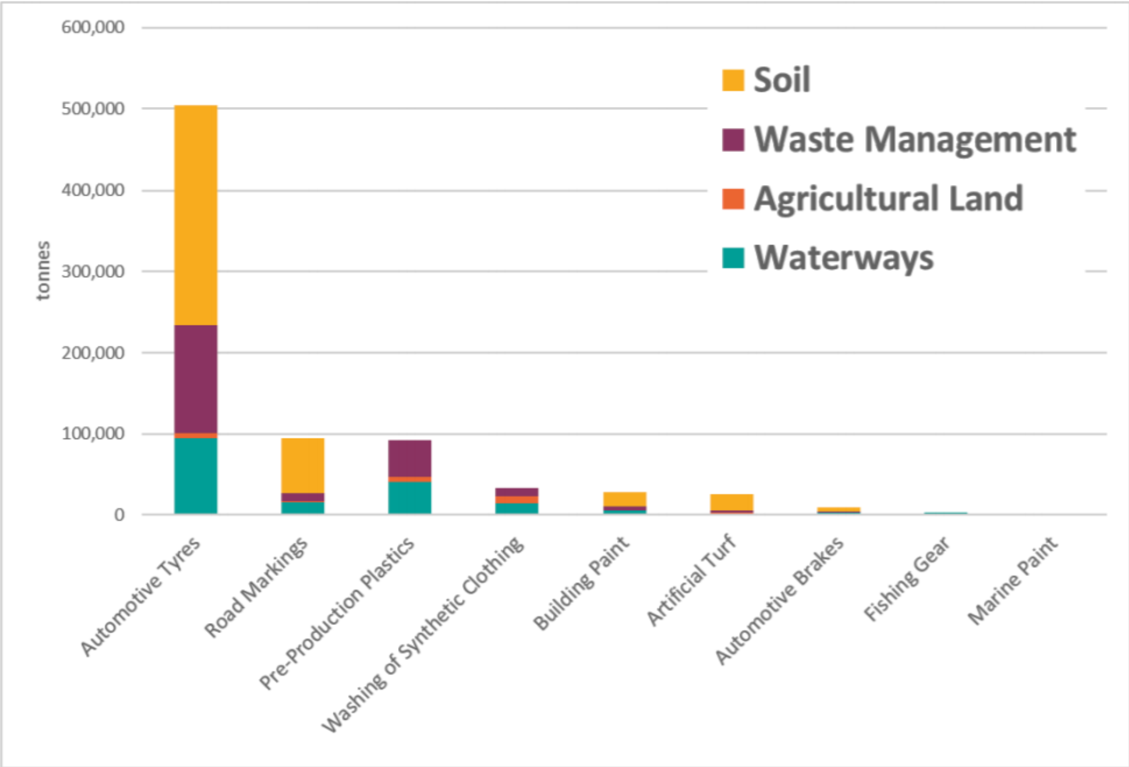
Microplastics, polymer particles less than 5 mm in size, are often categorized as primary (microplastics that are purposely manufactured in microscopic size to carry out a specific function) or secondary microplastics (representing the results of wear and tear or fragmentation of larger plastic items) (GESAMP 2016). According to a Danish assessment (Lassen et al. 2015), the emissions from primary microplastics sources would be 11% of the total emissions compared to 89% from secondary sources (excluding the formation from macroplastics) in Denmark. Furthermore, the share of primary microplastics releases ending up to the aquatic environment are estimated to be only 1% and secondary sources covering 99% of the emissions (Lassen et al. 2015). Tyres are estimated to cover 56% (4,200–6,600 t/year and 0.7–1.16kg/per capita/year) of the total emissions of primary and secondary sources followed by rubber granules (10.5%), textiles (6.2%), footwear, paints and other uses (approximately 5–6% each), road markings (4.1%), building materials from plastics (2.9%) and ship paints (2.4%) (Lassen et al. 2015, Sundt et al. 2016). Norway (Sundt et al. 2014) and Germany (Essel et al. 2015) have come up with similar estimates with tyre related emissions in their assessments of microplastic sources. However, many studies end up with a large range of estimated values together with high uncertainty for several sources and the formation of microplastics via fragmentation from macroplastics in the environment and the contribution of it to the total amount of microplastics is still poorly understood (HELCOM 2019).

It is worth emphasizing that the figures on car tyre and road wear microplastics presented in comparisons of different microplastics sources are based on various estimations and models, not on actual analytical data. Only a limited number of studies have quantified tyre and road wear particles in environmental samples, such as in road runoffs (Eisentraut et al. 2018).

Presently, there are no standardized methods for preparation and analysis of tyre and road wear particles. Analytical methods used to analyze tyre and road wear particles include methods based on microscopy, micro-spectroscopy (e.g. µ-Fourier transform infrared spectroscopy) and gas chromatography-mass spectrometry (e.g. pyrolysis GC/MS). However, these methods are both time-consuming and expensive. The present status of the methods for sample preparation and analysis of tyre and road wear particles has recently been reviewed by Andersson-Sköld et al. (2020).

Despite the uncertainty involved in the different estimates, it can be concluded that tyre emissions are significant and often the most important source of microplastics. This is also confirmed in the European Commission’s second report related to microplastics where tyre emissions are identified as the major source of non-intentionally added microplastics in the EU, 2018 (Eunomia & ICF 2018) (Figure 1).

The EU study on the sources of microplastics also concluded that the main sink of traffic microplastics is soil where microplastics are ending up after been washed away from roads. The particles may continue their way to watercourses over time. Other pathways of microplastics are road cleaning and different storm water systems that are considered under waste management. The efficiency of waste management methods depends heavily on whether they are managed properly.



Source: Eunomia modelling

Figure 1. Sources of non-intentionally added microplastics in the EU (Eunomia & ICF 2018).

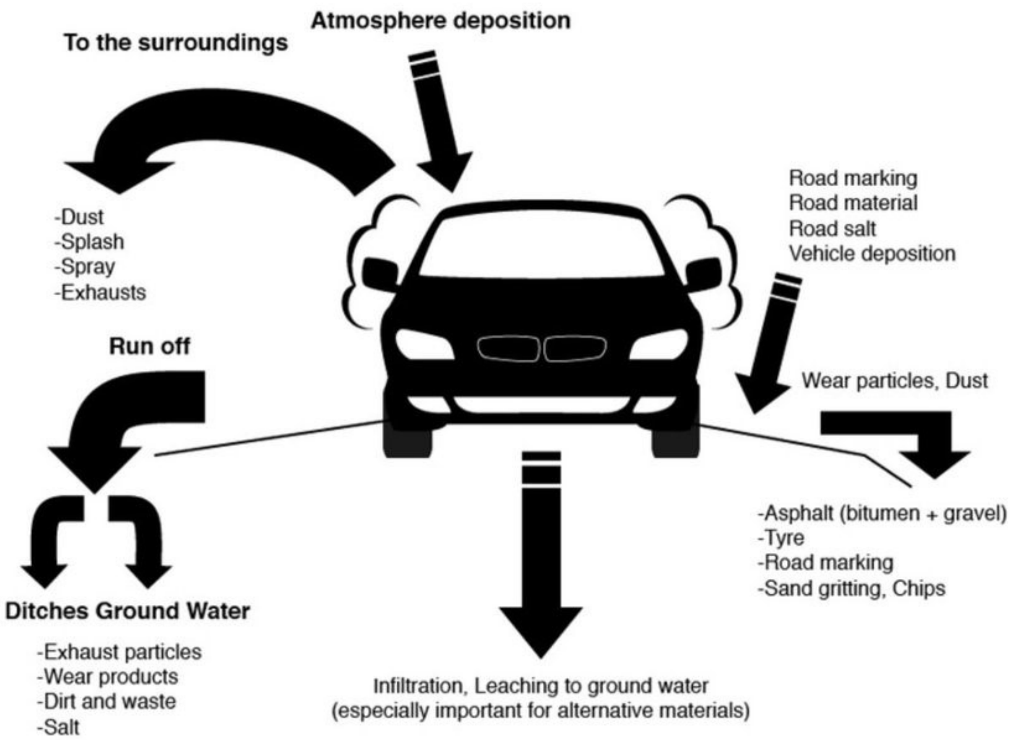


Figure 2. Sources of traffic derived pollutants (Vogelsang 2020, originally from www.roadex.com).

Traffic and road associated microplastics originate mainly from three sources: tyre tread, road markings (paint) and polymer modified bitumen (binding agent) in the asphalt (Andersson-Sköldt et al. 2020) (Figure 2). Tyre tread is the rubber part of the tyre. Polymer modified bitumen is the "glue" in the asphalt pavement that keeps the gravel together and it is also used to increase the strength, stability, and adhesive properties of the pavement under winter conditions (Jorgensen et al. 2016, Vogelsang et al. 2020). With road markings it is often referred to paints and they might include products such as thermoplastic systems, water/solvent based paints, 2-component systems, and road marking tape. These products can consist of plastic polymers, pigments, fillers, and additives (Andersson-Sköldt et al. 2020).

There are certain key factors influencing on how and where tyre and road wear particles are spread. These include the size, shape and density of the particles, the precipitation and dispersal pathways (Andersson-Sköld et al. 2020). Traffic microplastics may end up in the aquatic or terrestrial environments through many different pathways. These pathways include various transport and transformation processes influenced by different factors depending on local conditions making the overall picture very complex (Vogelsang et al. 2020). The potential dispersal pathways and transport processes for tyre and road wear particles can be seen in Figure 3.

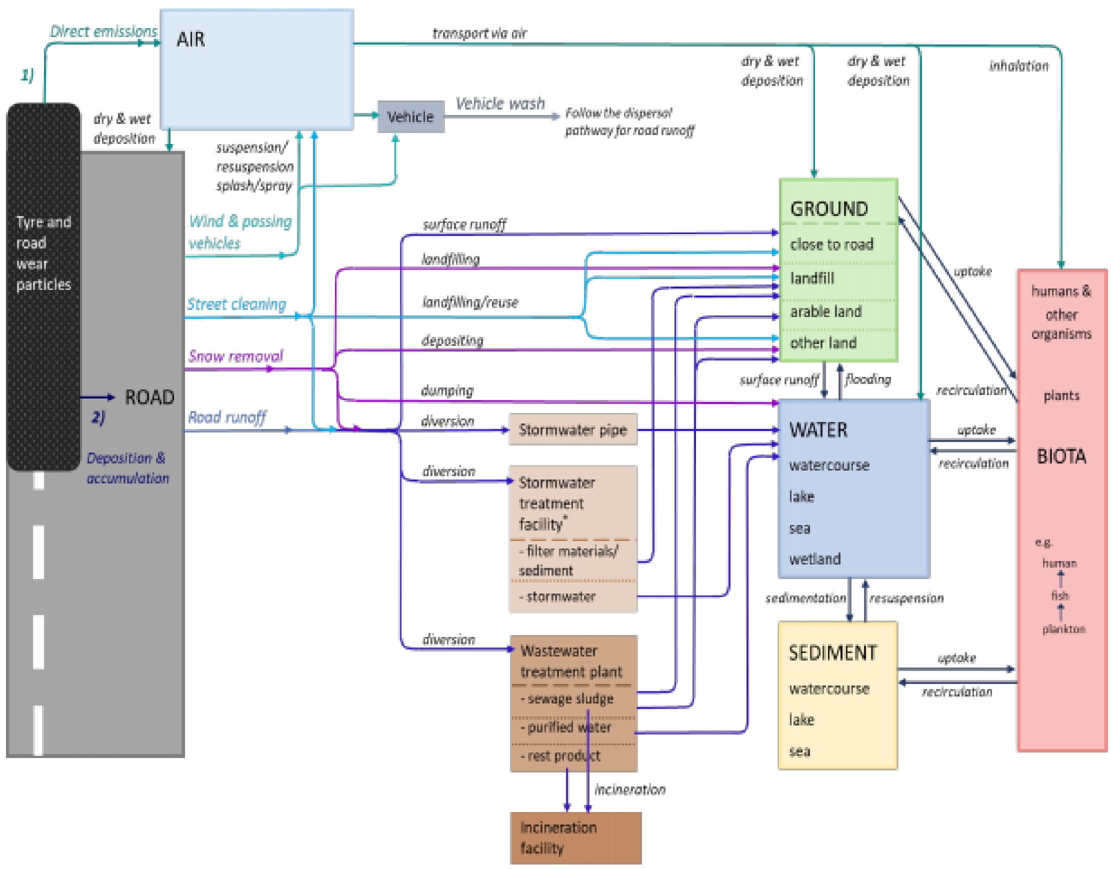


Figure 3. Potential dispersal pathways and transport processes for tyre and road wear particles (Delilah Lithner, VTI in Andresson-Sköld et al. 2020).

Figure 3 illustrates that tyre and road wear particles are formed in the contact between the tyre and the road and are then either released directly into the air or onto the road. Particles can then spread to different parts of the environment. This is dependent on the weather conditions as well as on the size and mass of the particle. Particles emitted to the air are either deposited to the road or at different distances from the road via dry or wet deposition. Those particles that are emitted to the road might accumulate on the road and stay there for different periods of time or travel through different dispersal pathways that can be via wind and passing vehicles, street cleaning, snow removal or road runoff. Road runoff may end up directly onto land or to the watercourses either through stormwater systems without or with treatment or through wastewater treatment facilities (Andersson-Sköld et al. 2020).

It should be noted that there are many knowledge gaps on what kind of proportions of traffic microplastics end up into different destinations: aquatic environments, soil, wastewater treatment plants and storm water systems. Information on the proportion of traffic microplastics released directly to the air and the proportion transported via road runoff is also unknown. In addition, the transportation patterns of different particles in different stages of their pathways are poorly understood. The lack of information makes the development and planning of mitigation measures difficult (Setälä and Suikkanen 2020).

There is no direct EU policy measure addressing the issue of traffic microplastics. In 2019, upon request from the European Commission, European Chemicals Agency (ECHA) proposed a restriction on intentionally added microplastics in products at the EU level and the restriction will be adopted in 2021 or 2022, if agreed by the European Commission and EU member states (ECHA 2021). However, this restriction concerns only primary microplastics and EU has planned to tackle the issue of plastic pollution more widely addressing both intentional and unintentional sources of microplastics. In relation to this, EU is preparing a consultation on the measures to reduce microplastics pollution from secondary sources (including car tyres). It will focus on labelling, standardization, certification, and regulatory measures for the main sources of these plastics. The public consultation for the initiative is planned for the third quarter of 2021 (EC 2021). Also, at EU level, there is no regulation on the minimum wear rate for tyres (Hann et al. 2018). Currently only fuel efficiency, wet grip and external rolling noise are considered.

2.2. Tyre composition

Tyres consist of an outer rubber layer (tread and sidewalls), several inner layers of different types of textile and steel, and an inner rubber layer (Figure 4). Tyre tread is the rubber part of the tyre that provides grip and traction on the road. It is from this part that tyre wear particles (i.e. rubber particles) are mainly generated during driving.

A wide range of chemicals can be found in vehicle tyres, depending on required performance standards and the manufacturing company. According to Continental (2021), their most popular summer tyre has the following composition:

- Rubber (natural and synthetic) 41%
- Fillers (carbon black, silica, carbon, chalk, etc.) 30%
- Reinforcing materials (steel, polyester, rayon, nylon) 15%
- Plasticizers (oils and resins) 6%
- Chemicals for vulcanization (sulphur, zinc oxide, etc.) 6%
- Anti-ageing agents and other chemicals 2%

A mixture of natural and synthetic rubbers is used in the tyre material. Carbon black is added to the rubber mixture as a filler to improve hardness, wear and UV-resistance. Carbon black can be partially replaced by silica or other materials. Silica reduces the rolling resistance, but it does not form as good bond to the rubber as carbon black. Plasticizers are used as softeners to provide elasticity and to improve the wet grip performance. Commonly used plasticizers are synthetic organic oils and resins. Vulcanization agents, such as sulphur, improve the elasticity and durability of tyre rubber. Zinc oxide serves as a catalyst in the vulcanization process (Kole et al. 2017).

In addition to rubber particles, tyre wear particles contain significant amounts of other hazardous compounds, such as zinc, silicon, and sulphur (Vogelsang et al. 2020). Tyre material contains about 1% zinc, which is present either as inorganic zinc (ZnO and ZnS) or in the form of organic compounds. Zinc is present in all particle sizes, but silicon is mainly present in airborne wear particles (Grigoratos and Martini 2014). Tyre wear particles contain also polycyclic aromatic hydrocarbons (PAHs), but the total content of PAHs in tyre wear particles is only ca. 5% of the total PAHs content of the road wear particles, while other sources, such as natural, asphalt, automobile exhaust and fuel combustion products, are the main PAHs sources (Grigoratos and Martini 2014).

It is estimated that an average passenger vehicle tyre lasts for 40,000–50,000 km before it is worn out, with approximately 10–30% of its tread rubber emitted into the environment (Grigoratos and Martini 2014). This depends on the tyre size, which has tended to increase over the years. Heavy vehicle tyres last longer, but on the other hand they emit approximately ten times higher amounts of tyre wear particles compared to light duty vehicles and passenger cars (Grigoratos and Martini 2014).

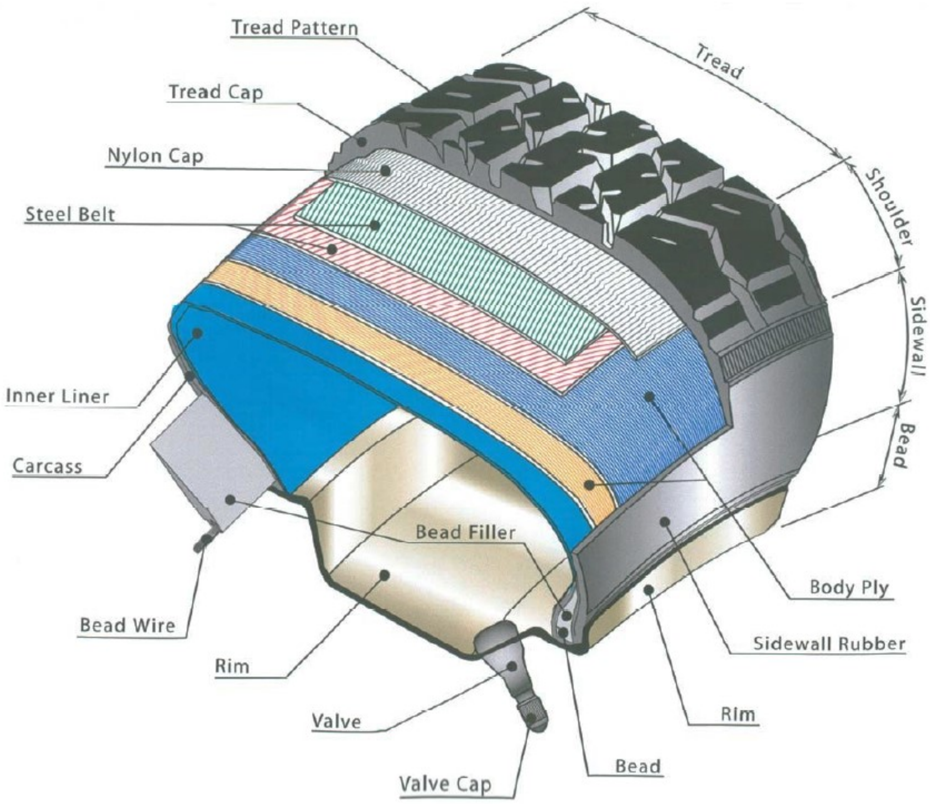


Figure 4. Tyre structure (Evans and Evans 2006).

3. Preventive methods

The most efficient ways to reduce the amount of tyre and road wear particles in the environment are through preventive methods (Sundt et al. 2016). Factors that affect tyre and road wear are related to proper use of tyres, driving behaviour, and the characteristics of the tyres as well as road surfaces (Table 1).

3.1. Proper use of tyres

To start with, a very basic thing to check is an optimal tyre pressure, which can be found from the car manual as well as the type of tyres suitable for the vehicle. The optimal tyre pressure varies with the load. It is recommended to check the tyre pressure with a three weeks interval and always before driving with heavy load (Nokian Renkaat 2021a). If the tyre pressure is too low, internal heat generation occurs, which increases the wear (Li et al. 2011). On the other hand, with too high pressure the tyre tread wears unevenly. The connection of tyre pressure, load on the tyre, driving speed and tyre dimension to tyre wear is also shown in a modelling study by Chen and Prathaban (2013). Whereas higher loads and speeds lead to increased wear, the wear decreases with higher air pressure, diameter, and width of the tyre tread.

In addition to tyre pressure, the steering angles of the tyres, i.e. wheel alignment, should also be checked regularly, e.g. once a year (Firestone 2019) This should be done at least visually based on tyre wear during service. Usually, the reason for the changed position of the wheel alignment is that the car has been driven to the edge of a cobblestone or a pit on the road. If the tyres are not properly aligned, the vehicle tends to pull to the left or right. However, the driver may not notice the fault other than as uneven tyre wear. Proper wheel alignment increases the lifetime of tyres, but also improves fuel efficiency and vehicle safety.

3.2. Driving behavior

Drivers can influence the tyre wear with their driving behavior. High speeds at highways, fast acceleration, heavy braking, and high cornering speed lead to increased tyre wear. Moreover, the effect of driver behavior on microplastic creation is exponential, e.g. the tyre wear is dependent on the vehicle speed in power four (Pohrt 2019). Therefore, a speed limit can be an effective measure for reducing tyre wear, but also educating drivers to better understand the consequences of their driving behavior. An example of the importance of driver behavior comes from Scania Group, where vehicles are equipped with monitoring devices. Overall, a 10-30 % of variation in fuel consumption can be attributed to driver-related factors (CGI 2014). Driving behavior contributes to tyre wear in the same way. Sundt et al. (2016) estimated that by avoiding unnecessary rough driving there would be a potential to reduce the tyre wear particle generation by 10%. An initiative for a tyre wear meter, "Ecometer", was even proposed during DEEP Microplastic Challenge 2019 (https://thinkcompany.fi/portfolio/microplastic/) an event organized as part of the FanpLESStic-sea project. The idea was to combine tyre wear with other driving-related factors in a similar manner than in a fuel consumption meter.

With an increasing number of electric vehicles on the roads, more attention should be paid to driving behavior regarding tyre wear. Electric cars can accelerate faster than many traditional cars, which may lead to increased tyre wear if this performance is used. In addition, electric cars are today generally heavier than cars that run on liquid fuels or gas, due to the weight of the batteries (Andersson-Sköld et al. 2020). The increased weight of a car is expected to lead increased wear and tear of tyres.

3.3. Tyre characteristics

Tyre characteristics, which affect tyre wear, include the chemical composition and pattern of the tyre tread. Currently, the EU tyre label focuses on three elements: fuel efficiency, wet grip and external rolling noise (Viegand Maagøe 2016). The aim is to guide both the manufacturers and customers towards more fuel-efficient tyres, as well as safe and quiet tyres. However, there is no EU regulation on the minimum wear rate for tyres (Hann et al. 2018).

Despite the lack of EU regulation, there are forerunners among tyre manufactures who have identified the problem with traffic microplastics originating from tyre wear. A Finnish company, Nokian Tyres has created a new more environmentally friendly product Nokian Hakka Green 3, which came to the market in 2020 (Nokian Renkaat 2021b). The new eco-design combines low rolling resistance with decreased tyre wear and fuel consumption. Test drives in Nordic countries and Russia shows 35% decreased tyre wear compared to the Nokia's previous corresponding model, which accounts to ca. 10,000 km depending on driving behavior (Tuulilasi 2020). Moreover, the product development has focused on the environmental sustainability of the materials as 100% biobased resin is used in the rubber blend of the tyre tread.

In Nordic conditions with seasonal variation, tyre characteristics vary also between winter and summer tyres. Winter tyres are made of a softer rubber mixture than summer tyres, to ensure they remain sufficiently soft at low temperatures. Summer tyres are made of a harder mixture, to prevent them from becoming too soft at higher temperatures (Andersson-Sköld et al. 2020). Thus, it is important to select right tyres according to weather conditions. For example, according to the current Finnish legislation, winter tyres must be used from the beginning of November until the end of March, if the weather requires it. It is worthwhile to emphasize that winter tyres, including non-studded ones, should not be used during summer – their performance is not for high temperature and their wear rate may be very high during summer.

Regarding studded tyres, they have been found to generate a significant amount of wear particles at the interface between the tyre and the road surface (Grigoratos and Martini 2014). When driving on snowy or slippery roads, the tyre tread pattern and the friction characteristics of the rubber are the main factors affecting traction. Non-studded winter tyres are also sometimes called friction tyres. Their grip characteristics are at their best on snowy roads. In very icy conditions studded tyres provide better grip and the best traction. Thus, most of the drivers (more than 80%) in Finland choose to use studded tyres. However, in the coastline of Southern Finland, winters are milder, and the roads are mostly kept in good conditions by removing snow and adding chemicals (so called salt). Thus, for local use in Southern Finland, non-studded winter tyres should be considered. City of Helsinki launched a campaign for non-studded winter tyres in October 2020 to increase the local share of non-studded winter tyres from 30% to 70% during the next ten years (City of Helsinki 2020).

In addition to microplastics from tyre wear, studded tyres in particular produce microplastics from road wear, more specifically from road markings and polymer modified bitumen, which is used in the asphalt (Andersson-Sköld et al. 2020). Lower shear of studded tyres would make it possible to use smaller stone size on road surface without sacrificing road wear. As already mentioned, smoother road surface with less damages would decrease tyre wear.

Table 1. Examples of factors that affect tyre wear.

Factor		Good practices	How to implement
Proper use of tyres:	tyre pressure	regular checking, varies also depending on the load	education for drivers
	wheel alignment	regular checking once a year, occasionally more often if needed	education for drivers, yearly inspections obligatory
Driving behavior:	fast acceleration and heavy braking, high cornering speeds	smoothly driving, tyre wear comparable to fuel consumption	education for drivers, fuel consumption/tyre wear meter
Tyre characteristics:	summer tyres, non-studded winter tyres, studded tyres	proper selection of tyres according to weather conditions and driving needs	local guidelines for tyre selection, public awareness raising campaigns
	tyre properties, eco-tyres	product development: chemical composition and pattern of the tyre tread	EU regulation for tyre wear, subsidies for eco-tyres (analogy with subsidies for electric vehicles)

4. Removal methods

The present report concentrates on preventive methods for traffic associated microplastics generation. In this chapter, measures for reduced dispersal of already emitted microplastic particles from car tyres are briefly reviewed. The existing methods for the removal of microplastic-containing road runoff particles are usually based on sedimentation, especially for larger and higher density particles. Filtration and adsorption are also important mechanisms especially for finer particles (Vogelsang et al. 2020, Andersson-Sköld et al. 2020).

4.1. Treatment solutions for stormwater

Urban and highway stormwater runoff are direct pathways for land based solid particles including microplastics and other traffic-borne particles into freshwaters. The traditional management practice for stormwater in urban areas has been to channel it in underground stormwater networks to the nearest waterbody without any treatment. Existing stormwater treatment technologies include wet and dry stormwater retention ponds, infiltration basins, constructed wetlands, and various filtration systems (Liu et al. 2019, Pankkonen 2020, Andersson-Sköld et al. 2020, Vogelsang et al. 2020).

Treatment methods for stormwater in urban areas are challenged by limited natural absorption degradation of surface runoff as well as limited space available for treatment units. Therefore, compact measures are required (Vogelsang et al. 2020). The stormwater management methods for separate sewer systems include roadside gully pots and various nature-based solutions (Vogelsang et al. 2020). Gully pots retain solids in urban road runoff and therefore prevent sediments from clogging the sewerage system. According to Vogelsang et al. (2020), common gully pots may retain a minor fraction of tyre wear particles larger that approximately 50 µm.

Nature-based solutions, so-called sustainable drainage systems in urban areas include infiltration chamber systems and dry swales (Vogelsang et al. 2020). Data on the efficiency of these stormwater treatment methods for removal of tyre associated microplastic particles is, to our knowledge, lacking.

In urban areas with a combined sewer system, stormwater runoffs end up in local wastewater treatment plants (WWTPs). In recent years, several studies have investigated the fate of microplastic particles during the wastewater treatment process. In general, up to 99% of microplastics in the influent are removed already during the primary and secondary treatment processes (Simon et al. 2018, Sun et al. 2019). However, no data on the removal efficiency of WWTPs for road traffic associated microplastics has yet been published (Vogelsang et al. 2020).

The primary treatment solutions for highway runoff include nature-based sedimentation ponds and technical treatment solutions, e.g. closed basins, and are used to settle the particle-associated pollutants. More advanced treatment options, filtration, sorption and biodegradation techniques can also be utilized (Vogelsang et al. 2020). The fate of traffic associated microplastics in these treatments has not been reported (Vogelsang et al. 2020).

4.2. Treatment of urban dust and snow

Street cleaning is used to reduce the amounts of dust and pollutants in urban air. Street sweeping has been shown to collect considerable amounts of tyre and bitumen microplastic particles.

Therefore e.g. weekly street sweeping might prevent transport of these microplastics via stormwater out in the environment (Järlskog et al. 2020).

Especially in Northern countries, particles from road traffic may accumulate in snow collected from roads and streets during winters. After ploughing, urban snow is collected to snow deposit sites from where it may end up in waterbodies or be directly dumped into the sea (Sund et al. 2016, Andersson-Sköld et al. 2020). Urban snow melting and filtering technology by Clewat Ltd is in piloting stage in Finland (Clewat 2021). However, the levels of traffic-associated microplastics in urban snow or removal efficiencies for that or other urban snow treatment solutions has not, to our knowledge, yet been published.

5. Recycling of car tyres

Each year, about 1 billion tyres are disposed worldwide (International Mining 2021). The disposal of tyres in the EU is regulated under directive 2000/53/EC End-of life vehicles. Tyres must be collected after use and processed by the manufacturer or the importer. Not only the use of tyres but also the end-of-life options may release microplastics. Thus, also the way how tyres are recycled should be paid attention to.

The recycling of tyres is challenging since tyres are composed of several materials. A tyre for a passenger car contains on average up to 25 components of different nature (mostly different types of reinforcement components, e.g. steel cords and different textiles), and the rubber part may contain 12 different types of rubber and chemical additives (Continental 2021).

A common way for recycling disposed tyres is grounding up to pieces between 0.7 and 3 mm and then using as infill in artificial turfs and related areas (Kole et al. 2017). In addition, the ground up tyres have been used as filling material for urban areas and mixed with the asphalt. However, in recent years, concern has arisen about the spread of microplastics in the environment from reuse of ground up tyres. In 2019, the European Chemicals Agency (ECHA) proposed a restriction on microplastics in products at EU level. A ban for microplastics used as infill material on artificial turf pitches was recommended, with a transition period of six years. As another option, the mandatory use of risk management measures, such as fences and brushes to prevent the emission of granules, was evaluated. If agreed by the European Commission and EU member states, the restriction will be adopted in 2021 or 2022 (ECHA 2021).

Thus, new solutions for recycling tyre material are needed. In Finland, Suomen Rengaskierrätys Oy is now building a new recycling plant in Loppi (Kemia 2020). The plant will start operation in the beginning of 2023 and have a capacity to treat 20,000 t of disposed tyres per year, which equals to one third of yearly disposed tyres in Finland. The process is still based on grounding, but the particle size is smaller and different materials will be separated from each other. The main product is rubber powder which can replace natural rubber in many applications such as insulation, sealing, rubber boots or ice hockey puck.

Michelin, the world largest tyre manufacturer since 2020, will use even more advanced pyrolysis technology for tyre recycling. They have announced the construction of a new-generation end-of-life tyre processing plant in Chile (Michelin 2020). The plant project is implemented in collaboration with the Swedish company Enviro that has developed a technology to recover carbon black, pyrolysis oil, steel and gas from end-of-life tyres. The plant will be able to recycle 30,000 t of earthmover tyres a year, or nearly 60% of such tyres scrapped every year in Chile. The work will begin in 2021, with the production scheduled to start in 2023.

6. Conclusions

This report focused on preventive methods for decreasing microplastics from tyre wear. Removal methods were also briefly discussed. However, it is both costly and difficult to remove microplastics once released to the environment. Preventive methods are cost-effective and most of them are not dependent on further technology development. Thus, preventing or reducing the formation of tyre and road wear particles is the first option, and the second option stopping or decreasing spreading to the environment.

Preventive methods discussed in this report were the proper use of tyres (regular checking of tyre pressure and wheel alignment), driving behavior (avoiding fast acceleration and heavy braking), and tyre characteristics (non-studded vs. studded tyres, "eco-tyres" with less wear). In addition to decreasing microplastics from tyre wear, these measures can provide additional benefits such as improved air quality in cities, improved safety in traffic, decreased noise pollution, and decreased fuel consumption and greenhouse gas emissions.

But how to implement these measures and change the driver behavior? A good starting point is more comprehensive education for drivers and public awareness raising campaigns. Local guidelines would be beneficial for supporting the selection between non-studded and studded tyres for winter use. Fuel consumption meters could be recommended as part of instrumentation in the car. In addition to guiding the drivers towards more economic driving, they would also lengthen the lifetime of tyres and decrease the tyre wear. Some improvements would also need supportive policies for their implementation. Tyre pressure is easy to check by individuals, but wheel alignment must be checked by professionals. Because it is an extra cost and not required, it is often overlooked. However, proper wheel alignment is critical regarding tyre wear and thus yearly inspections should be made obligatory. Tyre labels should include a standardized wear rate marking. Currently only fuel efficiency, wet grip and external rolling noise are considered. And finally, there could be subsidies for "eco-tyres" respectively as for electric vehicles to improve the technology development and market penetration of tyres, which wear less and contain less hazardous compounds.

However, with preventive methods it is only possible to reduce tyre wear particle emissions and not totally avoid them. Thus, also removal methods are needed to capture tyre wear particles. They are not yet that much in use and their availability is also restricted. Thus, further research is needed to develop both environmentally friendly and cost-effective methods. An additional treatment method requires also raw materials and energy and causes emissions. The benefits of removing microplastics should be greater than the environmental load of additional resources use and emissions due to their removal. Treatment methods should be also cost-effective for a wide implementation.

Finally, the development and harmonization of sampling, sample preparation and analytical methods suitable for tyre and road wear particles is needed to better evaluate and understand the problem. Both the piloting of removal methods and the development of analytics for tyre wear particles are carried out during the on-going FanpLESStic-sea project and will be reported separately.

The primary aim of the EU's 'Sustainable and Smart Mobility Strategy' is to reduce transport related greenhouse gas (GHG) emissions by at least 90% by 2050 compared to 1990. However, a carbon neutral transportation system is not enough, also other traffic related contamination, such as tyre and road wear particles should be considered. A good way forward to tackle this problem is public awareness raising. There is already a lot that can be done even without further technical development. However, commitment is needed from all stakeholders; policy makers, industry, municipalities and consumers.

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