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Reducing the Release of Microplastic from Tire Wear: Nordic Efforts

Report prepared by Ingvild Skumlien Furuseth and Elisabeth Støhle Rødland

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Summary

Tire wear is the single most important source of microplastic particles in the Nordic countries. Commissioned by the Nordic Working Group for Circular Economy (NCE), NIVA has assessed the Nordic efforts on microplastic leaching from tire wear to the marine environment. This report addresses five key questions; what measures have been identified, what actions have been taken, how has the work been organized, which good practices can be instructive, and what recommendations can be made for the Nordic countries? Our findings indicate that none of the Nordic countries have implemented specific measures against microplastic leaching from roads to the marine environment. Targeted efforts against particle pollution from road and tire wear in general may cover microplastic as well. The report describes relevant measures and their implementation in the Nordic countries and provides recommendations for future work.

Four keywords	Fire emneord
1. Tire wear	1. Dekkslitasje
2. Microplastic	2. Mikroplast
3. Road pollution	3. Veiforurensning
4. Policy measures	4. Tiltak

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Ingvild Skumlien Furuseth	*Sondre Meland*
Main author	Research Manager

Preface

Commissioned by the Nordic Working Group for Circular Economy (NCE), NIVA has assessed Nordic actions against microplastic leaching from tire wear to the marine environment, and recommended actions for further work. The project was founded by the Nordic Council of Ministers.

The work was conducted in the period July-November 2020. Main authors were Ingvild Skumlien Furuseth and Elisabeth Støhle Rødland, while Sondre Meland was the project leader. Members of the NCEs Waste-Subgroup were the project's Steering Group, led by Marianne Reime who was the contact point.

This report has benefitted from contributions made by public servants in environmental and road administrations in the Nordic region (Norway, Sweden, Denmark, Finland and Iceland). Thanks to everyone who contributed with useful information and input through interviews, questionnaires, email contact, and meetings.

Oslo, December 1, 2020

Ingvild Skumlien Furuseth

Table of contents

Summary **5**

Sammendrag **6**

Acronyms **7**

1 Introduction **8**

2 Methods **9**

3 Actions against microplastic from tire wear **10**

3.1 Reducing microplastic emissions from tire wear – Nordic efforts 10

3.1.1 Enhancing tire wear resistance 11

3.1.2 Optimising vehicle use and maintenance 12

3.1.3 Road surface and maintenance 18

3.2 Capturing emitted microplastic from tire wear – Nordic efforts 19

3.2.1 Transport pathways 19

3.2.2 Handling of road runoff 20

3.2.3 Wastewater treatment 31

3.2.4 Requirements and standardized methods 32

3.3 Europe: status and experiences 33

3.3.1 Reducing microplastic emissions from tire wear 33

3.3.2 Capturing emitted microplastic from tire wear 34

4 Recommendations **35**

5 References **37**

Summary

Tire wear is the single most important source of microplastic particles in the Nordic countries. Commissioned by the Nordic Working Group for Circular Economy (NCE), NIVA has assessed the Nordic efforts against microplastic leaching from tire wear to the marine environment.

The main source of tire wear to the marine environment are likely untreated runoff from roads with direct discharge to the marine recipient, such as tunnel wash water or runoff from major roads where the drainage system has discharge directly to the recipient. According to our findings, none of the Nordic countries have implemented specific measures against microplastic leaching from roads to the marine environment. However, targeted efforts against particle emission and pollution from road and tire wear in general may reduce the emissions of microplastic as well. Efforts to reduce local air pollution caused by road dust will likely also reduce microplastic emissions, a component in road dust. Relevant examples are environmental speed limits (ESL), reduction in traffic volume and limits to use of studded tires. Norway has implemented ESL, while several countries have addressed studded tires. Reducing the traffic volume is a strategy sought by all Nordic countries.

Current knowledge of tire wear particles, microplastic particles and general road pollution indicates that a large fraction of particle-related pollution is retained in the roadside area and in any treatment that has sufficient capacity for sedimentation from runoff. Treatment of runoff, particularly in “hot-spots”, can be a cost-effective method of reducing microplastic emissions to the environment. However, our findings suggest that the countries probably have far fewer treatment systems for road runoff in place than needed (e.g., for tunnel wash water), and the maintenance and testing of existing treatment systems are deficient. Studies on wastewater treatment plants indicate that tire particles likely are also retained, mainly in the sludge. Sewage sludge is often used as fertilizer in agriculture, thus the potential of a second pathway from farmland to marine recipients also exists through agricultural runoff and should be addressed.

We recommend the following actions:

- In collaboration with the research community, continued focus on the development of standardized analytical methods for quantifying tire particles in environmental samples.
- Studies on the mass flow of tire wear particles. This should be included in monitoring programmes and research projects on retention in different environmental compartments.
- Incorporation of appropriate requirements for water treatment of road and tunnel runoff in discharge permits, based on updated knowledge.
- Continued research on the efficiency of retention for various water treatment techniques, so that future projects may choose the most optimal design to capture microplastic particles.
- Investigation of the adequacy of the proposed measures and policy instruments to reduce microplastic pollution, including their cost-effectiveness and co-benefits. Implications for other policy areas should be considered.
- Knowledge sharing and collaboration between countries. We encourage the Nordic countries to follow and contribute to developments at the EU level (e.g., standard wear test, tire label, regulations).

Sammendrag

Tittel: Reducing the Release of Microplastic from Tire Wear: Nordic efforts
År: 2020
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På oppdrag fra Nordisk arbeidsgruppe for sirkulær økonomi (NCE) har NIVA undersøkt statusen for de nordiske landenes arbeid mot utslipp av mikroplast fra dekkslitasje til det marine miljø, og kommet med forslag til videre arbeid på dette området. Oppdraget har bakgrunn i at dekkslitasje regnes som den største kilden til mikroplast i miljøet i disse landene.

Hovedkilden av dekkslitasje til det marine miljø vil trolig komme fra urenset veivann med direkte påslipp til marin resipient. For eksempel tunnelvaskevann eller avrenning fra større veier hvor drenssystemet har påslipp direkte til resipient. Våre undersøkelser viser at ingen av landene har implementert tiltak eller virkemidler direkte rettet mot mikroplast fra dekkslitasje. Men tiltak mot generell partikkelforurensning fra veg- og dekkslitasje, vil trolig også fungere mot mikroplast. Reduksjon av mikroplast fra dekkslitasje omfattes trolig av dagens tiltak mot lokal luftforurensning og svevestøv hvor mikroplast trolig er en komponent. Eksempler på slike tiltak er miljøfartsgrenser, redusert bruk av piggdekk og generell reduksjon av trafikkvolumet. Norge bruker miljøfartsgrenser i utvalgte områder, mens flere av landene gjør andre tiltak for å redusere bruken av piggdekk. Alle de nordiske landene søker å redusere trafikkvolumet.

Dagens kunnskap om dekkpartikler, mikroplastpartikler og generell veiforurensning indikerer at en stor andel av partikkelrelatert forurensning vil bli holdt tilbake i sideterrenget og i rensesystemer for veivann som har tilstrekkelig kapasitet til å sedimentere avrenningen. Men landene har trolig langt færre rensesystemer for veivann på plass enn det som er hensiktsmessig (f.eks. for tunnelvaskevann), og oppfølgingen og testingen av eksisterende rensesystemer er mangelfull. Videre indikerer funn fra studier på renseanlegg fra avløpsanlegg at disse trolig klarer å håndtere mikroplast fra dekkslitasje ved at det samles opp i slammet. I og med at slam ofte brukes som gjødsel i jordbruket, kan dette føre til spredning av mikroplast fra jordbruk til miljøet. Dette bør undersøkes nærmere og adresseres.

Vi anbefaler følgende handlinger:

- Fortsett arbeidet med å utvikle en standardisert analysemetode for kvantifisering av dekkpartikler, i samarbeid med forskningsmiljøet.
- Kunnskapsbygging på massestrømmen av partikler fra dekkslitasje. Det bør inkluderes i overvåkingsprogrammer, samt forskningsprosjekter om tilbakeholdelse i ulike miljø.
- Inkluder passende krav til rensing av vei- og tunnelavrenning i utslippstillatelser, basert på oppdatert kunnskap.
- Fortsett forskning på effektiviteten av tilbakeholdelse av mikroplastpartikler i ulike renseløsninger slik at fremtidige prosjekter kan velge det optimale designet for å fange opp mikroplastpartikler.
- Undersøk om de foreslåtte tiltakene og virkemidlene er tilstrekkelige for å redusere mikroplastforurensning, samt deres kostnadseffektivitet og andre fordeler. Implikasjoner for andre politikkområder bør vurderes.
- Kunnskapsdeling og samarbeid mellom land. Vi oppfordrer de nordiske landene til å følge og bidra til utviklingen på EU-nivå (f.eks. standard for testing av dekkslitasje, merkeordning for dekk, lovverk).

Acronyms

AADT	Annual Average Daily Traffic
ABS	Anti-lock braking systems
EAI	Environment Agency of Iceland
EC	European Commission
ESC	Electronic stability control
ETRMA	European Tire and Rubber Manufacturers' Association
FTIA	Finnish Transport Infrastructure Agency (Väylävirasto)
IVL	Swedish Environmental Research Institute (Svenska Miljöinstitutet)
MET	Norwegian Meteorological Institute (Meteorologisk Institutt)
NCE	Nordic Working Group for Circular Economy
NEA	Norwegian Environment Agency (Miljødirektoratet)
NIPH	Norwegian Institute of Public Health (Folkehelseinstituttet)
NORWAT	Nordic Road Water (https://www.vegvesen.no/en/professional/focus-areas/research-and-development/completed-projects/norwat)
NPRA	Norwegian Public Roads Administration (Vegdirektoratet)
OECD	Organisation for Economic Co-operation and Development
REHIRUP	Reducing Highway Runoff Pollution, R&D project funded by NordFoU (www.nordfou.org/)
SEA	Swedish Energy Agency (Energimyndigheten)
SEPA	Swedish Environmental Protection Agency (Naturvärdsverket)
STA	Swedish Transport Administration (Trafikverket)
TPMS	Tire Pressure Monitoring System
VTI	Swedish National Road and Transport Research Institute (Statens väg- och transportforskningsinstitut)
WBCSD	World Business Council for Sustainable Development

1 Introduction

Microplastic pollution has received global attention in recent years due to the massive amounts of both macroplastic (>5mm) and microplastic (1nm to 5 mm) found in the environment (GESAMP, 2016). There have been several studies investigating the sizes of plastic debris; several size definitions exist (Hartman et al., 2019). This sparked large-scale investigations into the sources of plastics to the environment. From these investigations, tire wear particles (TWP), generated from the abrasion of tires on the road surface, have been estimated to be the single most important source of microplastic particles in several countries, including the Nordic countries (Dahlbo et al., 2020; Järlskog et al., 2020; Lassen et al., 2015; Sigurðsson & Halldórsson, 2019; Sundt et al., 2014; Sundt et al., 2016; Vogelsang et al., 2019). Several studies have reported concentrations of tire particles in the environment (Bye & Johnsen, 2019; Klöckner et al., 2019; Unice et al., 2013; Wik & Dave, 2009). There is still an urgent need, however, to establish standardized methods for quantifying tire particles in the environment and to investigate various environmental compartments relevant to road runoff in order to quantify the amount of tire particles transported from road surfaces to the surrounding areas. There is also the need to evaluate the efficiency of various measures to limit tire particle production and transport.

Potential measures to address the issue of TWP leaching to the environment have been proposed in several reports (Andersson-Sköld et al., 2020; Verschoor et al., 2016; Verschoor & de Valk, 2018) and at a recent workshop hosted by the OECD and WBCSD (2020). Efforts can address emissions themselves, i.e. the production of TWP, or prevent dispersion of emitted particles. Here we will identify measures implemented in the Nordic countries, highlight good practices and give recommendations for future actions. Several of the actions suggested in this report will not only be beneficial for the measures against TWP (including microplastic), but all road dust related pollution (from the road surface and markings etc.). An assessment of benefits and costs of the suggested measures is not part of our study but should be conducted before adopting such measures, in order to choose the most cost-efficient measures and policy instruments.

This report is the result of a project commissioned by the Nordic Working Group for Circular Economy (NCE) under the Nordic Council of Ministers. The aim was to identify measures in the Nordic region to prevent leaching of microplastic from tire abrasion into the marine environment. This report will address five key questions;

- what measures have been identified?
- what actions have been taken?
- how has the work been organized?
- which good practices can be instructive?
- what recommendations can be made?

2 Methods

We approached the questions raised by the NCE through a literature review and contacts with public servants in the environmental and road administrations in the Nordic region (Norway, Sweden, Denmark, Finland and Iceland).

First, a literature search was conducted to collect relevant reports, scientific articles, policy documents, webpages, etc. We identified potential contact persons through our previously established contacts and relevant reports, as well as suggestions from representatives of the NCE, existing contacts and through snowball sampling[1]. Then, potential contact persons were approached by e-mail to gather relevant literature and information from their respective countries. Finally, we received responses from representatives from all countries we approached.

After initial processing of gathered literature and information, we circulated a questionnaire to our contact persons in the environmental and road administrations in all Nordic countries[2]. The questionnaire was answered by the environmental administrations of Norway and Iceland, as well as from the road administrations of Norway, Sweden and Finland. Unfortunately, not everyone answered our questionnaire, or answered in detail, thus there are some uncertainties in the material. We addressed this uncertainty by supplementing the material with information retrieved from public authorities' webpages, reports and scientific literature found on the internet. Overall, the information we got from Norway and Sweden were more comprehensive than for the other Nordic countries, which is why we mostly focus on measures in these two countries.

The work was conducted in the period July-November 2020.

[1] Snowball sampling refers to the method of recruiting informants through suggestions from previously recruited informants.

[2] The questionnaire was circulated by e-mail to all countries; the Swedish Transport Administration was interviewed using similar questions in a video call.

3 Actions against microplastic from tire wear

None of the Nordic countries reported having implemented specific measures against microplastic leaching from roads to the marine environment. The issue, however, is of growing concern. All countries have conducted emission studies to calculate the annual emission of road-related microplastic and several have included knowledge-based measures in their reports (Dahlbo et al., 2020; Lassen et al., 2015; Sigurðsson & Halldórsson, 2019; Sundt et al., 2014; Sundt et al., 2016; Vogelsang et al., 2019). Most of the suggested measures are without scientific documentation on their efficiency for tire wear particles. They are, however, presented as possible measures based on the efficiency for removing road pollution in general. The removal of particle pollution from road runoff and tunnel wash water is especially important to include in this work. Road pollution is handled differently across European countries, in terms of planning, construction and managing treatment facilities for road pollution (Andersson et al., 2018; Meland, 2016). Amongst the Nordic countries, Norway, Sweden and Denmark appear to have invested much more in treatment facilities than Iceland and Finland.

Governmental decisions should be well-founded and thought through. Sufficient knowledge about emissions and effects of microplastic, as well as on the effects of various measures, is needed to adopt measures against microplastic from tire wear. Furthermore, cost-efficiency is important in decision-making, thus the effects of suggested measures should be compared with the associated costs, i.e., socioeconomic, investment, maintenance and administrative costs. An assessment of benefits and costs of suggested measures is not part of our report but should be conducted before adopting measures.

3.1 Reducing microplastic emissions from tire wear – Nordic efforts

Efforts can be taken to reduce emissions from tire wear directly, in addition to capture emitted particles. Targeting the cause of pollution is generally considered the preferred option, but not always achievable. In this chapter, we will present measures targeting the emissions from tire wear directly, and what actions have been taken by the Nordic countries.

The road transport sector is one of the main contributors to local air pollution, both for NO_2 and suspended particulate matter (especially PM_{10}). In that regard, measures taken to comply with legislation related to local air pollution are highly relevant, e.g., the EU air quality directive (2008/50/EC) which applies to the Nordic countries. Therefore, it is crucial to consider not just the effects of microplastic emissions, but also particular matter in general generated from tire wear, when considering which measures to implement.

Likewise, efforts to reduce GHG emissions from road transport can affect the emissions of microplastic from tire wear. Some efforts, such as reducing road traffic in general, ensuring optimal tire pressure and wheel alignment, eco-driving practices and environmental speed limits, can have positive effects on GHG emissions and also reduce TWP emissions. The increasing use of electrical cars can worsen tire wear because electrical cars are generally heavier and have higher torque than similar sized fossil-fueled cars (Andersson-Sköld et al., 2020; OECD & WBCSD, 2020). Thus, co-benefits and negative side effects on particle emissions from tire wear should be taken into account when considering climate measures for the road transport sector.

None of the Nordic countries, to our knowledge, has specifically estimated the reduction potential of suggested measures with regard to microplastic emissions from tire wear. A Dutch study has estimated such reduction potentials (Verschoor & de Valk, 2018), but did not consider measures against emissions from studded tires, which is highly relevant in the Nordic context. Considering the lack of knowledge on the effects of various measures, we cannot conclude which measures, relevant for the Nordic countries, are most efficient against *microplastic* from tire wear. Cost-effectiveness studies for measures against road dust pollution in general may be relevant, such as the recent study by the Norwegian Governmental Air Quality Collaboration (NEA et al., 2020); unfortunately, this was a study of the effects of a combination of measures, not individual measures/efforts. Cost-benefit studies encompassing all relevant measures against microplastic from tire wear should be conducted to aid decisions as to which measures to implement.

The following sections describe potential actions and policy instruments aimed at limiting microplastic pollution from tire wear and provide an overview over such efforts made by the Nordic countries.

3.1.1 Enhancing tire wear resistance

Enhancing tire wear resistance will reduce emissions of TWP directly but should not be sought at the expense of safety. In the Nordic region, this strategy has been identified in Norway (NEA, 2016; NEA, 2019b; NEA, 2020; Sundt et al., 2016; Vogelsang et al., 2019) and Sweden (Andersson-Sköld et al., 2020; SEPA, 2017; STA, 2019).

Two options have been proposed:

1. Adopting a legal threshold value for tire wear
2. including wear rates in tire labels.

Verschoor and de Valk (2018) estimated that either measure could reduce emissions to water by 200 tonnes/year in the Netherlands, while Hann et al. (2018) estimated that the combined measures could reduce emissions to surface water by 23 %.

A standardized wear test is crucial to adopt tire wear as a factor in regulations or labels. Hann et al. (2018) pointed out that major brands have developed their own testing procedures which they may be reluctant to forego because embracing a common standard may involve revealing sensitive data or break the continuity of test data. Moreover, adopting a common standard for tire wear may also allow for testing wet grip, rolling resistance and noise over the lifespan of tires, which will be of benefit to consumers, according to Hann et al. (2018). At present, these properties are tested mainly on new tires.

In their plastic strategy from 2018[3], the European Commission stated that they would consider using labelling and specific requirements for tires. To support free movement of goods, they specified that a tire standard should be developed at EU level[4]. The following year, an EC regulation on tire labelling was adopted, allowing for extending the tire labelling scheme to include tire wear as an indicator when a standardized measurement method is available[5]. Work is underway at the European Commission to develop such method for emission from brakes and tires (questionnaire, NPRA). Nordic countries' authorities such as the Norwegian Public Roads Administration (NPRA) and the Swedish Energy Agency

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A28%3AFIN
[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=SWD:2018:16:FIN&from=EN
[5] https://www.consilium.europa.eu/en/press/press-releases/2020/02/25/labelling-of-tyres-council-adopts-new-rules/

follow the development of this process (NEA, 2020; SEPA, 2017). Whether Finland, Iceland and Denmark have made efforts to enhance tire wear resistance is unknown to us.

3.1.2 Optimising vehicle use and maintenance

Optimal tire pressure and wheel alignment

Tire pressure and wheel alignment are factors influencing the tire wear rate (Andersson-Sköld et al., 2020; OECD & WBCSD, 2020; Verschoor et al., 2016; Verschoor & de Valk, 2018). Tires with too low air pressure are worn down faster than with optimal pressure, while too high pressure leads to excessive inner wear, according to Andersson-Sköld et al. (2020).

In the EU, tire pressure monitoring systems (TPMS) are mandatory for new passenger cars registered from November 2014, according to the EU Directive 2010/48/EU. Sweden did not implement the directive as the Swedish Transport Administration (STA) argued that tire pressure is sufficiently controlled when changing between summer and winter tires (Andersson-Sköld et al., 2020). Moreover, Sweden have no requirements for controlling the TPMS in cars with such systems installed[6]. Norway[7], Denmark[8] and Finland[9] implemented mandatory TPMS in accordance with EU Regulations. Whether Iceland has implemented EU regulations with regard to TPMS is unknown to us.

The EU directive does not apply to older cars. Verschoor and de Valk (2018) found that installing TPMS in older passenger cars would have a reduction potential of 70 tonnes/year in the Netherlands, compared to 100 tonnes/year if TPMS was installed in all passenger cars. The Nordic countries could consider assessing the current status on tire pressure in their car fleet, and if deemed cost-effective, take action to ensure optimal tire pressure in older cars as well.

Stricter control of wheel alignment is another measure suggested by Verschoor and de Valk (2018) and Andersson-Sköld et al. (2020). Properly aligned tires wear less than tilted tires. Controlling wheel alignment is part of mandatory periodic vehicle inspections in accordance with the EU Directive 2014/45/EU, which is implemented in Norway[10], Sweden[11], Finland[12], Denmark[13] and Iceland[14]. Serious misalignment provides a basis for a deficiency notice or driving ban.

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[6] https://www.transportstyrelsen.se/sv/vagtrafik/Fordon/Fordonsregler/allmant-for-vagfordon/Dacktrycksovervakningssystem/ (last updated 13 June 2014; read 17 October 2020)

[7] According to NPRA's answer to our questionnaire.

[8] https://daeksikkerhed.dk/tpms (read 17 October 2020)

[9] https://arkisto.trafi.fi/uutisarkisto/2742/rengaspainevahdit_tulevat_uusiin_autoihin_marraskuussa (read 17 April 2020

[10] According to NPRA's answer to our questionnaire. Implemented in Regulation no. 591 of 13 May, 2009 (Forskrift om periodisk kjøretøykontroll): https://lovdata.no/dokument/SF/forskrift/2009-05-13-591.

[11] Implemented in regulations: Transportstyrelsens föreskrifter och allmänna råd om kontrollbesiktning (TSFS 2017:54)

[12] Implemented in regulations: Bedömningsgrunder vid periodisk besiktning av fordon (TRAFICOM/540030/03.04.03.00/2019)

[13] Implemented in law: Lov om godkendelse og syn af køretøjer, bilag 1

[14] Implemented in regulations: Reglugerð um breytingu á reglugerð nr. 8/2009 um skoðun ökutækja.

Winter and studded tires

Use of studded tires is by far the most important cause of road wear, although the wear rate depends on a range of factors related to the vehicle and the tire as well a local conditions (Lundy et al., 1992, cited in ; Vogelsang et al., 2019). While non-studded tires polish the surface, studded tires roughen it. Lowne (1970, cited in Vogelsang et al. 2019) found large variations in tire wear depending on road surface, for which rough, harsh surfaces caused more severe tire wear. This has been difficult to verify in subsequent studies due to limitations of study designs and difficulties of isolating other factors (Vogelsang et al., 2019). Nevertheless, it is probable that use of studded tires has an effect on the road surface, which in turn leads to more tire wear, in addition to release of microplastic from polymer-modified asphalt and road markings (Andersson-Sköld et al., 2020). Whether studded tires themselves wear more or less than non-studded tires is currently unknown. A larger scale study of different types of tires would be beneficial. Compared to *summer tires*, non-studded winter tires generally have a softer quality to get proper grip and are therefore more suseptible to abrasion (Vogelsang et al., 2019).

Safety is the main argument for using studded tires, while the effects on environment and human health argues for reducing the use of studded tires. Climate, topography, traffic volume, infrastructure and other local conditions determine to what extent decreasing the use of studded tires is feasible and desirable (NEA et al., 2020). The STA (2019) recently stated that they need further measures on a national level to reduce emissions from studded tires, in order to meet the evironmental quality objectives for clean air. Sweden initially chose not to implement any general policy instruments against studded tires due to safety reasons, according to an interviewee from STA. Their decision was supported by the results of an (now) old life cycle assessment (LCA). The interviewee further explained that subsequent technology developments such as anti-lock braking systems (ABS) reduced the need for studded tires. Another relevant technology development is electronic stability control (ESC). Elvik (2015) found that full adoption of ESC can reduce the use of studded tires to about 15 % before any increase in the number of accidents occurs. If all cars had ESC and studded tires were permitted, on the other hand, the number of accidents with injuries could be reduced by 9-10 % in the winter season. (Elvik, 2015).

A thorough assessment of the costs and benefits of reducing the use of studded tires for human health and the environment, as well as administrative costs, is required to help the Nordic countries decide whether to reduce the use of studded tires. The Norwegian Governmental Air Quality Collaboration conducted such an assessment of measures, using DALY[15] for impacts on human health, to decide whether the limit values for PM_{10}, $PM_{2.5}$ and NO_2 should be lowered (NEA et al., 2020). The assessement, which included efforts to reduce the use of studded tires, concluded that their suggested package of measures indeed was socially profitable. Furthermore, a recent LCA on studded tires specifically found that negative impacts on human health of particle emissions from studded tires outweigh the health benefits of fewer passenger car accidents causing human death or disability (Furberg et al., 2018). Considering the results of these studies, efforts to limit the use of studded tires may be relevant in Sweden as well other Nordic countries.

The following sections describe various policy instruments implemented in the Nordic countries that can reduce TWP emissions from winter and studded tires.

[15] Health benefits and costs are measured in DALY, which gives the number of years lost because of premature death and/or the number of years lost because of disability.

Regulations related to winter tires

Using winter tires is mandatory in all Nordic countries when driving under winter conditions[16]. Non-studded winter tires are generally allowed all year round, while studded tires are only permitted in a specific period in the winter season and when required by weather or road surface conditions. This specific period varies somewhat between countries, but lasts typically from November to March/April.

Considering that winter tires abrade more than summer tires, restricting the use of winter tires outside season is an important measure to reduce microplastic emissions from tire wear. The Nordic countries could consider monitoring the use of non-studded winter tires in summer time, and if deemed cost-effective, prohibit the use of non-studded tires in the summer season when local conditions do not require winter tires.

Taxation on the use of studded tire

Taxation on studded tire usage is another option that can discourage consumers from using studded tires. In Norway, this measure can be adopted by municipalities if air quality standards on particulate matter is not fullfilled. The measure needs approval from NPRA or the Ministry of Transport[17]. Several Norwegian cities, including Trondheim (2001)[18], Oslo (2004)[19] and Bergen (2006)[20], have implemented such taxes, with relatively good results. NPRA found that 91 % and 89 % of passenger cars in Oslo and Bergen respectively used non-studded tires in 2019, compared to 66 % and 69 % in 2001[21]. Generally, the number of non-studded tires in use is higher in the Oslo region and further south than the other parts of Norway. In Tromsø, located far north where winter conditions are tougher and last longer, only 17 % of passenger cars used non-studded tires in 2019, compared to almost 10 % in 2008, the lowest percentages in the cities monitored. The NPRA has proposed that the Ministry of Transport make changes to the tax regulation on studded tires to make it more flexible and more relevant for other cities in order to reduce local air pollution levels (PM_{10}) (NPRA, 2020a, NEA et al. 2020). The proposed changes will also provide incentives for drivers to change from studded tires to summer tires earlier in the year when driving conditions allow. Norway is the only Nordic country to have implemented taxation on the use of studded tires.

Ban on studded tires

A temporary or permanent ban on studded tires in some streets or areas is yet another option. Finland has recently adopted new regulations in the Finnish Road Traffic Act allowing for a ban on studded tires on some roads. The city of Helsinki is considering this (questionnaire, FTIA). Permanent bans on

[16] Norway: https://www.vegvesen.no/en/vehicles/own-and-maintain/tyres-and-chains
Sweden: https://www.transportstyrelsen.se/en/road/vehicles/winter-tyres
Finland: https://www.traficom.fi/en/transport/road/winter-tyres
Denmark: https://fdm.dk/alt-om-biler/test-udstyr/daek/regler-vinterdaek-danmark-andre-lande
Iceland: https://www.icetra.is/road-traffic/how-to-drive-in-iceland/

[17] Regulation no. 437 of 7 May, 1999 (Forskrift om gebyr for bruk av piggdekk). https://lovdata.no/dokument/SF/forskrift/1999-05-07-437

[18] Implemented in 2001 until 2010. Then re-introduced in 2015. Current regulation is Regulation no. 2094 of 19 October, 2020 (Forskrift om piggdekkgebyr, Trondheim): https://lovdata.no/dokument/LF/forskrift/2020-10-19-2094

[19] Regulation no. 1358 of 13 October, 2004 (Forskrift om piggdekkgebyr, Oslo): https://lovdata.no/dokument/LF/forskrift/2004-10-13-1358

[20] Regulation no. 1162 of 31 August, 2006 (Forskrift om piggdekkgebyr, Bergen): https://lovdata.no/dokument/LF/forskrift/2006-08-31-1162

[21] https://www.vegvesen.no/om+statens+vegvesen/presse/nyheter/nasjonalt/stadig-flere-velger-piggfrie-vinterdekk

studded tires have also been implemented on some roads in Stockholm (from 2010)[22] and Gothenburg (from 2011)[23]. The city of Trondheim (in Norway) has adopted, but not implemented, temporary prohibitions on studded tires in the city center as an immediate measure when PM_{10} levels are likely to exceed the limit values, a prohibition which is based on the Road Traffic Act, article 7 (NEA et al., 2020). Generally, municipalities and the NPRA can adopt similar temporary prohibitations, in accordance with the same statutory authority. Whether Iceland and Denmark have implemented bans on studded tires is unknown to us.

Design of studded tires

The design of studded tires may also have an impact on the amount of road dust generated. NPRA collaborated with partners in Sweden and Finland regarding development of legislation on design of studded tires (NPRA, 2020a). Any change in legislation is not expected before 2022-2033 at the earliest, because it must be coordinated with all Nordic countries and the tire industry must have time to adapt to new legislation. Whether Iceland and Denmark have made efforts with regard to the design of studded tires is unknown to us.

Environmental speed limits

Speed limits are normally implemented as a traffic safety measure, for which the desired speed limits are determined by local conditions (Lopez-Aparicio et al., 2020). However, speed limits can also be lowered to reduce local air pollution. Reducing the speed can improve the driving efficiency, thus reduce NO_2 emissions from exhaust and reduce tire and road wear, the main contributors of PM emissions from road transport (Lopez-Aparicio et al., 2020). Moreover, vehicle traffic at high speed stirs up more road dust than at low speed. Speed not only influence the rate of emissions, but also how its spread. The NPRA has nearly two decades of experience with environmental speed limits (ESL), and these are considered most suitable for roads with high speed and traffic volume in a dry climate with buildings close to the road (NEA et al., 2020).

In Norway, ESL was first proposed in an emergency plan of the city of Oslo in 1998 to bring down air pollution levels but was not implemented due to high administrative costs (NPRA, 2012). Then, in 2004 and 2005, the NPRA tested ESL in the winter season as measure to reduce air pollution on National Road 4 (Sinsen – Grorud) in Oslo, combined with taxation on the use of studded tires. Later, ESL was introduced on the ring road 3 (Ryen – Granfosstunnelen) in Oslo in November 2006 and on E18 (Hjortnes – Lysaker, from 6 AM to 10 PM) in November 2007 (NPRA, 2012). In 2012, the speed limit was lowered permanently to 70 km/h, due to several legal reasons (Norman et al., 2016). Recently, the Norwegian Governmental Air Quality Collaboration suggested introducing ESL in Fredrikstad and Lillehammer as well (NEA et al., 2020).

[22] https://trafik.stockholm/trafiksakerhet-trafikregler/dubbdack/ (read 16 October 2020)
[23] https://goteborg.se/wps/portal?uri=gbglnk%3agbg.page.d123dc51-93fb-46af-853e-9e069bc5929d (read 16 October 2020)

Figure 1. Environmental speed limits (miljøfartsgrense) at State Road 4 in Oslo, Norway. (Photo: Knut Opeide/Statens Vegvesen)

The results of studies on the effect of ESL on air pollution levels are not consistent. Modelled estimates of Norman et al. (2016) showed that the combined measures of introducing taxation on studded tires and lowering the speed limit from 80 to 60 km/h at State Road 4 reduced the mean PM_{10} concentrations in nearby air by 38 % and 26 % in 2005 and 2006, respectively. Although the speed limits were reduced by 20 km/h, the actual average speed changed only from 75 to 65 km/h. In comparison, Lopez-Aparicio et al. (2020) found much smaller emission reductions in their models for National Road 4, the ring road 3 and E18 corresponding to 5 % and 2 % for PM_{10} and $PM_{2.5}$ respectively (scenario 2: observed speed after implementing ESL) and 12 % and 6 % for PM_{10} and $PM_{2.5}$ respectively (scenario 3: fully compliance with ESL). However, when they compared observed emission levels in years with and without environmental speed limits, the PM_{10} emission reductions corresponded to 17-28 % for three out of four stations, while the fourth station did not show any changes, probably because of high congestion levels. They conclude that environmental speed limit is an effective measure to reduce PM_{10} levels, when compliance is ensured and the degree of congestion in rush hours is low. Folgerø et al. (2020) found that the expected effect of the ESL policy, based on their estimations, was about zero for PM_{10} and $PM_{2.5}$, which differs from the results of the studies in Oslo (Lopez-Aparicio et al., 2020; Norman et al., 2016). They conclude that authorities should find other measures to reduce local air pollution. The findings of Folgerø et al. (2020) are based on a previous study which has been criticized by specialists on local air pollution at the Norwegian Institute for Air Research and the NPRA[24].

[24] Bentzrød, S.B. 2017, 6.11. Masteroppgave: Miljøfartsgrense har ingen miljøeffekt. Aftenposten. Retrieved from https://www.aftenposten.no/norge/i/m74qv/masteroppgave-miljoefartsgrense-har-ingen-miljoeeffekt (read 19 October, 2020)
Bentzrød, S.B. 2017, 7.11. Handelshøyskolen ga Aftenposten gale tall om miljøfartsgrense. Aftenposten. Retrieved from https://www.aftenposten.no/norge/i/8bArr/handelshoeyskolen-ga-aftenposten-gale-tall-om-miljoefartsgrense (read 19 October, 2020)
Høiskar, B.A.K, Tønnesen, D. and Walker, S.-E. 2017, 8.11. Joda, miljøfartsgrensen virker. Aftenposten.

Norway is the only Nordic country we found to have implemented environmental speed limits. Finland has not implemented environmental speed limits per se (questionnaire, FTIA), but reduces speed limits on motorways in wintertime for safety reasons[25]. In Sweden, the STA are adjusting speed limits for safety reasons and to reduce the impact on climate[26]. Nordic countries without any speed-adjustments in wintertime could consider whether environmental speed limits would appropriate for them as well, to reduce microplastic emissions and air pollution levels.

Eco-driving practices

Rapid acceleration and deceleration are tougher for tires and road surfaces, thus likely to cause more abrasion (Andersson-Sköld et al., 2020). Efforts to support eco-driving practices have been suggested in several reports (Andersson-Sköld et al., 2020; Sundt et al., 2016; Verschoor & de Valk, 2018). The term "eco-driving" has been used to explain a variety of driving behaviors, typically to reduce fuel consumption (Sanguinetti et al., 2017). The definitions of eco-driving seem to contradict each other — gentle, moderate and fast acceleration have all been put forward as eco-driving. For tire and road wear, the term eco-driving generally refers to smooth acceleration, deceleration and speed in general, as well as fewer starts and stops.

Eco-driving can be supported through efforts to improve driver awareness and behavior or infrastructural measures (e.g., traffic planning, lower speed limits) that allow for better traffic flow. In Norway, the NPRA emphasized increased focus on eco-driving to reduce plastic pollution in their input to the new national transport plan (NPRA, 2020a). They mentioned lower speed limits, better training and control of driving behavior, and autonomous vehicles as potential contributions to improving the traffic flow. In Sweden, the STA adjust speed limits for safety reasons and to reduce the impact on climate[27]. Adjusting speed limits because of concern for climate could influence the emission of TWP as well, depending on how the speed limits are adjusted. As for the remaining Nordic countries, we identified no examples of eco-driving.

Reducing road traffic volume

Reducing the road traffic volume is an important strategy sought by the Nordic countries in urban areas to reduce GHG emission from road transport[28], improve local air quality and public health. A range of measures can be implemented to reduce traffic volume, with various policy instruments at different governmental levels. Cars as means of transport can be discouraged by several kinds of taxes and fees, impaired mobility and fewer parking spaces, or limited by regulations. Alternatively, public authorities can encourage the use of public transport, bicycling and walking by offering services and building and maintaining infrastructure so these means of transport are chosen rather than cars. Moreover, travel-free meetings, teleworking and e-commerce offer alternatives to travel. These measures can have co-benefits, such as reduced emissions of TWP. But some measures to bring down GHG emissions, for

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Retrieved from https://www.aftenposten.no/meninger/debatt/i/gXqPB/jo-da-miljoefartsgrensen-virker-hoeiskar-toennesen-og-walker (read 19 October, 2020)

[25] https://vayla.fi/sv/vagnatet/drift-och-underhall/hastighetsbegransningar (read 19 October 2020)

[26] https://www.trafikverket.se/resa-och-trafik/trafiksakerhet/Din-sakerhet-pa-vagen/Hastighetsgranser-pa-vag/Nya-hastighetsgranser/ (read 19 October 2020)

[27] https://www.trafikverket.se/resa-och-trafik/trafiksakerhet/Din-sakerhet-pa-vagen/Hastighetsgranser-pa-vag/Nya-hastighetsgranser/ (read 19 October 2020)

[28] The transport sector is responsible for 27 % of GHG emissions in the European Union, of which 72 % are from road transport. Source: https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12

example, can result in more tire wear. The use of electrical vehicles which tend to be heavier and have higher torque than similar sized fossil fuel cars could increase emissions of TWP (see next chapter).

The Icelandic government issued a new transport plan for 2020-2034 and action plan for 2020-2024[29], in which environmentally-friendly transportation is among five main objectives. Their strategy is to promote public transport and bicycling as means of transportation to reduce passenger car traffic (questionnaire, EAI). Similar strategies have been implemented in Sweden, Norway and Finland (Ljungblad & Nilsson, 2014, questionnaire, NPRA, FTIA). The Norwegian goal for urban areas is to reduce GHG emissions, traffic queues, air pollution and noise through efficient land use, and by public transport, cycling and walking rather than cars comprising the expected growth in passenger transpart (Ministry of Transport and Communications, 2020, questionnaire, NPRA). Finland is also encouraging other means of transport by among other measures favoring busses at traffic signals, building and maintaining bicycle routes (questionnaire, FTIA). Swedish authorities focus on energy efficiency and renewable energy as strategies against GHG emissions in the transport sector, and lack policy instruments that can reduce road traffic volume, according to the Swedish Climate Policy Council (2019). On the local level, some Swedish cities, e.g. Linköping, make efforts to reduce traffic volume to reduce PM_{10} and NO_2 emissions from road transport (Ljungblad & Nilsson, 2014). Reducing traffic volume is also seen as an important measure to reduce GHG emissions in the transport sector (STA, 2016; Swedish Climate Policy Council, 2019). The Swedish Climate Policy Council (2019) recommended that Swedish authorities make efforts to support a more transport-efficient society where more trips are taken by bicycle, walking and public transport. This could have an effect on the emissions of TWP as well, including microplastic.

Further investigations are needed to understand whether implemented measures have in fact reduced the road traffic volume or will be able to. NEA et al. (2020) estimated the reduction potential to air (PM_{10}) of reducing traffic volume, but did not estimate the cost-efficiency. Adding to the work of NEA et al. (2020), the reduction potential to other pathways should also be estimated in order to understand this strategy's full potential to reduce leaching of microplastic from tire wear to the marine environment. Moreover, the measures to reduce road traffic volume should be seen in relation to policy objectives related to public health, environment and climate, as these areas can benefit from such measures. An holistic socio-economic assessment of various alternatives (measures), which includes their co-benefits and costs, should be conducted in order to decide which alternative should be implemented through which policy instrument.

Reverse current trend towards heavier vehicles and faster acceleration

A side effect of the current trend of adopting electrical cars can be an increased tire wear caused by heavier weight and higher torque than similar sized fossil-fuel cars (Andersson-Sköld et al., 2020; OECD & WBCSD, 2020). Participants at the recent workshop arranged by OECD and WBCSD (2020) suggested further research on the effect electrical cars have on tire wear. This could be followed by research on how to overcome these effects on tire wear.

3.1.3 Road surface and maintenance

The road design and surface composition are regarded as yet additional factors affecting the degree of tire wear, and consequently several reports suggest improving the road design and surface (Verschoor et al., 2016; Andersson-Sköld et al., 2020; OECD and WBCSD 2020). Verschoor et al. (2016) listed alternatives such as developing road surfaces that minimize abrasion or hold/filter TWP, and

[29] https://www.stjornarradid.is/verkefni/samgongur-og-fjarskipti/samgonguaaetlun/samgonguaaetlun-2020-2034

timely road maintenance. We found no clear evidence of Nordic countries improving the road design or surface for the purpose of reducing microplastic emissions from tire wear. However, our project did not investigate this in detail, so we cannot rule out that some Nordic countries made efforts to reduce pollution from tire wear by improving road surface, design or maintenance.

3.2 Capturing emitted microplastic from tire wear – Nordic efforts

3.2.1 Transport pathways

When a tire particle has been created on the road surface, the fate of this particle can be quite different, and depending on a whole range of different factors. As indicated in Figure 2, we can consider five main pathways for a tire particle: 1) Retention on the road surface, 2) Atmospheric transport, 3) Roadside deposition, 4) Runoff to road and tunnel drainage systems, and 5) Runoff to sewage systems and Wastewater Treatment Plants (WWTP). The real-life pathway pattern of tire particles may, however, be far more complicated than depicted in this figure, and there is still a knowledge gap as to where the tire particles end up in the environment and the mass balance of tire particles from the road to different environmental compartments.

A tire particle can accumulate on the road surface, especially on the edges of the road (Pathway 1). From here it may be removed by road sweeping and dust collection or may take a new pathway. One major factor impacting transport pathways is the size of the particles. Small particles, such as PM_{10} (<10µm), become airborne to a large extent (Pathway 2). About 10% of the tire particles are estimated to be in this size range (Boulter et al., 2006). They can be airborne from minutes to several hours and spread up to 50 km away from roads (Kole et al., 2017). Tire particles that are deposited close to the road may end up in the road verges (Pathway 3) by splashing or overflowing from the road to the sides during precipitation events. Precipitation will further transport tire particles to the nearest drainage system of that road. In some areas, this can be a drainage system installed especially for the road system (Vogelsang et al., 2019) (Pathway 4) or it can be linked to the domestic sewer system (combined sewer system) (Pathway 5). The latter is more common in larger cities, where there are many impervious surfaces. The road drainage system might also have treatment measures for the runoff before it is released into a recipient, however, in most cases it will be released untreated.

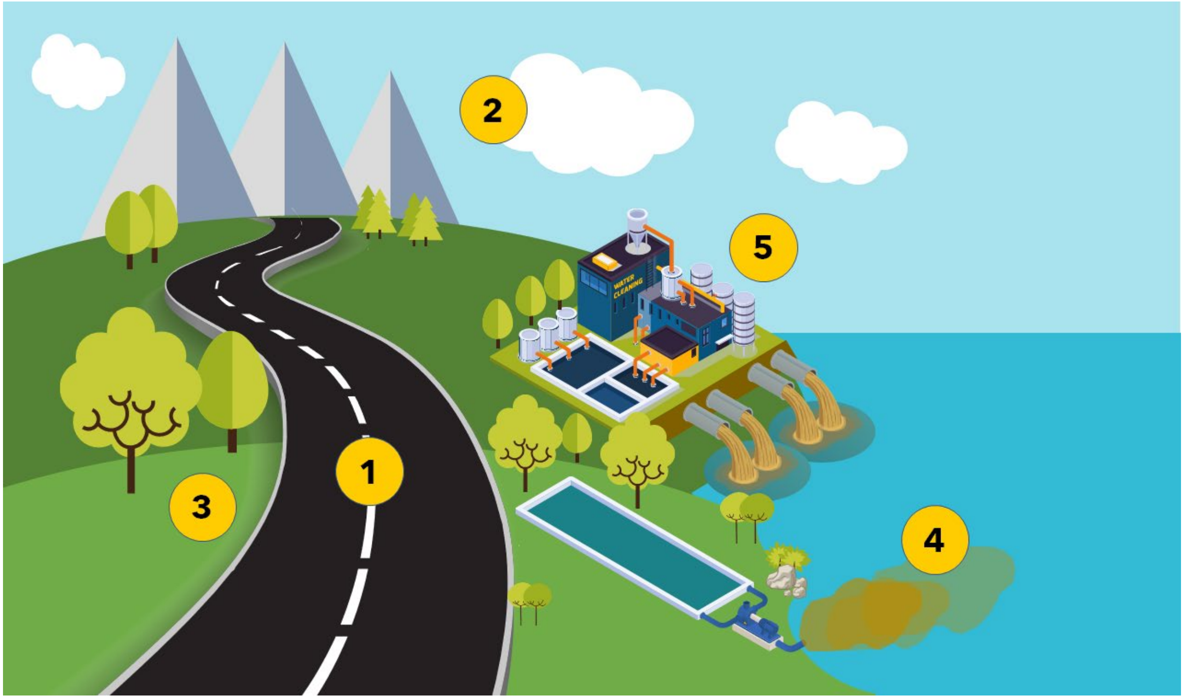

Figure 2. Illustration of the five main pathways for tire particles from the road surface to the environment. 1) Retention on the road surface, 2) Atmospheric transport, 3) Roadside deposition, 4) Runoff to road and tunnel drainage systems 5) Runoff to sewage systems and Wastewater Treatment Plants (WWTP) (Illustration: E. Rødland)

3.2.2 Handling of road runoff

Road cleaning

The transport path of tire particles is important for the runoff management. For any road system, it is necessary to know which path is most likely for the road runoff and adjust the management activities accordingly. The first possible measure would be to collect TWP from the road surface before they are transported away, corresponding to Pathway 1 (Figure 2). This can be done with an increased road sweeping and road dust collecting. It is common practice in Norway to sweep, wash and clean the road network in the spring to remove the accumulated road dust from the winter season, including sand and gravel that may have been used for traffic safety measures. The Norwegian Environment Agency (NEA) recommend contracts for road cleaning which consider local conditions rather than regulating road cleaning through legislation (NEA, 2019b). Each road owner (municipalities, NPRA and the counties) are responsible for their own road system. For tunnels (Figure 3), this cleaning procedure is done on a more regular basis, depending on the volume of traffic. Some are cleaned once every few years and some up to 12 times per year. For Norwegian state and county roads, the general road cleaning procedures are described in R610 (NPRA, 2014).

The efficiency of road and tunnel cleaning is dependent on the methods and the equipment used. There have been several tests of different types of sweepers, with and without vacuum suction, use of water etc. Collaborations between the NPRA and the entrepreneur market have facilitated a development in this area, and the efficiency of various types of cleaning equipment have been tested, showing that the design of the equipment highly influences the effectiveness of removal of road dust from streets (Snilsberg et al., 2018). Similar studies have also been performed in Sweden (Järlskog et al., 2017; Polukarova et al., 2020), and these showed that nano- and micro-sized particles can also be removed with certain types of cleaning equipment. In the study of Aronsson et al. (2018), it was also reported that road cleaning possibly can remove microplastic particles, including tire rubber and bitumen particles >100 µm, as visual inspection of particles showed morphology consistent with tire particles and bitumen particles. However, the study did not include analytical methods to confirm that these particles comes from tires or the mass of tire particles collected in the cleaning. There is still a need for developing equipment and methods and for documentation of the efficiency of these in retention of road dust in general and tire particles in particular. However, it will not be possible to collect all tire particles this way, as they are generated non-stop if there are cars on the road. So, adding other measures to collect the tire particles before they are released into the environment are necessary.

Figure 3. Example of road dust accumulating on the roadsides of a tunnel, illustrating the need for periodic road cleaning (Photo: E. Rødland)

Snow removal

Studies have shown that urban snow can accumulate contaminants such as zinc (Zn), lead (Pb), polycyclic aromatic hydrocarbons (PAH) and particles (Figure 4) (Bækken, 1994; Hautala et al., 1995; Kuoppamäki et al., 2014; Moghadas et al., 2015; Ranneklev et al., 2013; Ranneklev, 2016). Recent studies also reported microplastic particles in snow, both in urban snow and rural snow (Bergmann et al., 2019; Vijayan et al., 2019). Management practices vary, but snow removal is often needed in densely populated areas, while the snow is left on the roadside in rural areas. The contaminants spread through the local dispersal pathways during snowmelt. Historically, snow removals have often been dumped on nearby land or into watercourses, lakes and the ocean, and constitute a source of water pollution. The NEA states that the County Governor has the delegated authority through the Pollution Control Act 1981 in Norway to evaluate areas for snow deposits and issue permits for deposits and the resulting runoff (NEA, 2019a). The NPRA states that they follow the restrictions of the Pollution Control Act and have no specific regulations of their own with respect to contaminated snow (Questionnaire, NPRA, 2020). There are currently 10 permits issued for snow deposits in Norway, six in the Oslo and Viken county and four in Trøndelag county (www.norskeutslipp.no). Of the ten permits given, three permits require measuring microplastic in runoff and the sediments from the snow deposit. All of these were set by the County Governor in Trøndelag. Microplastic was mentioned in some of the permits, as one of the pollutants that might be present in the snow. However, there were no requirements set for measuring it or any limits for microplastic amounts in runoff or sediments.

Figure 4. Example of snow accumulating in roadsides, with dark color indicating presence of road dust (Photo: E. Rødland)

Dust binding

Dust binding with magnesium chloride or other chemicals can be applied to roads as a measure to reduce air pollution. Gustafsson et al. (2017) found that dust binding could be an important measure in the spring, but should be employed with proper timing, when needed, as a supplement to other measures earlier in the season that prevent accumulation of road dust on the surface (Gustafsson et al., 2019). Dust binding, however, does not remove the particles which can be transported by stormwater to the local dispersal pathways (Andersson-Sköld et al., 2020).

Sedimentation traps/gully-pots

The TWP that is not removed from the road surface with the road cleaning or snow removal measures, may continue on its path to a gully-pot, which is common for larger roads and in cities (Figure 5). These gully pots are used to retain sediments to avoid clogging of the sewer system (Lindholm, 2015). Gully pots are effective for large (>80 µm) and heavy particles. However, gully pots retain only about 8%, 10% and 20% of the tire particles in road runoff if the water flow into the gully pot is 25L/s, 15L/s and 5L/s, respectively (Vogelsang et al., 2019). The faster it flows, the more difficult it will be for the tire particles to settle and be retained in the gully-pot. Also, all gully-pots need to be maintained and emptied before reaching 50% capacity or maximum up to 20 cm below the outlet, for them to have a sufficient retention (Lindholm, 2015; Mosevoll & Lindholm, 1986; NPRA, 2014). Handbook R610 (NPRA, 2014) describes the maintenance of gully-pots. Oslo city alone has approximately 30 000 gully-pots (Ræstad, 2014), and keeping up with the maintenance on these gully pots is a challenging task. Still, the maintenance of gully-pots is mentioned as a prioritized task by the Norwegian Environment Agency (NEA, 2019a) and proposed to be included in updates of the Pollution Control Act 1981.

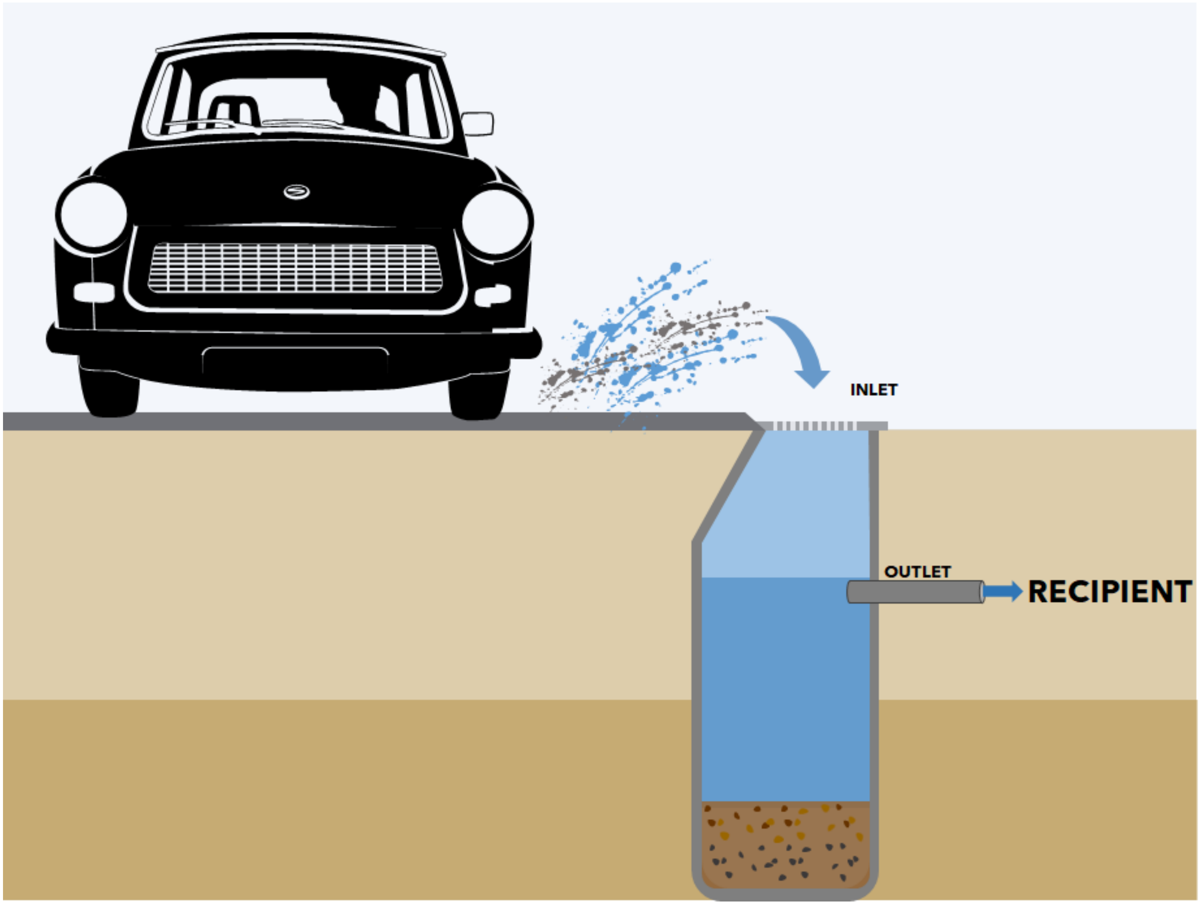

Figure 5. Conceptual illustration of a gully-pot used for retention of road runoff (Illustration: E. Rødland, car from freepik)

Roadside swales

For many road systems, there are no drainage system and most of the runoff will end up in swales along the roads (Pathway 2, Figure 6). These swales are designed to transport the road runoff away from the road by infiltration in the ground or as an open water system to a nearby recipient (Vogelsang et al., 2019). There are currently no studies published on how well the TWP is retained in these swales. There are, however, studies that have assessed the retention of road pollutants in general, and it depends on how these swales are built (Åstebøl et al., 2011, Åstebøl and Hvitved-Jacobsen, 2014). One study reported up to 70% removal of suspended solids (Åstebøl and Hvitved-Jacobsen, 2014). More knowledge is needed to evaluate the retention of TWP in these swales and if there are certain swale designs that might be more efficient than others. Swales that are designed to remove water by infiltration may become clogged by sediment from runoff inputs, and the sediment must be replaced to ensure optimal function. Material removed may contain TWP and other road contaminants, and it is important to ensure correct handling after removal.

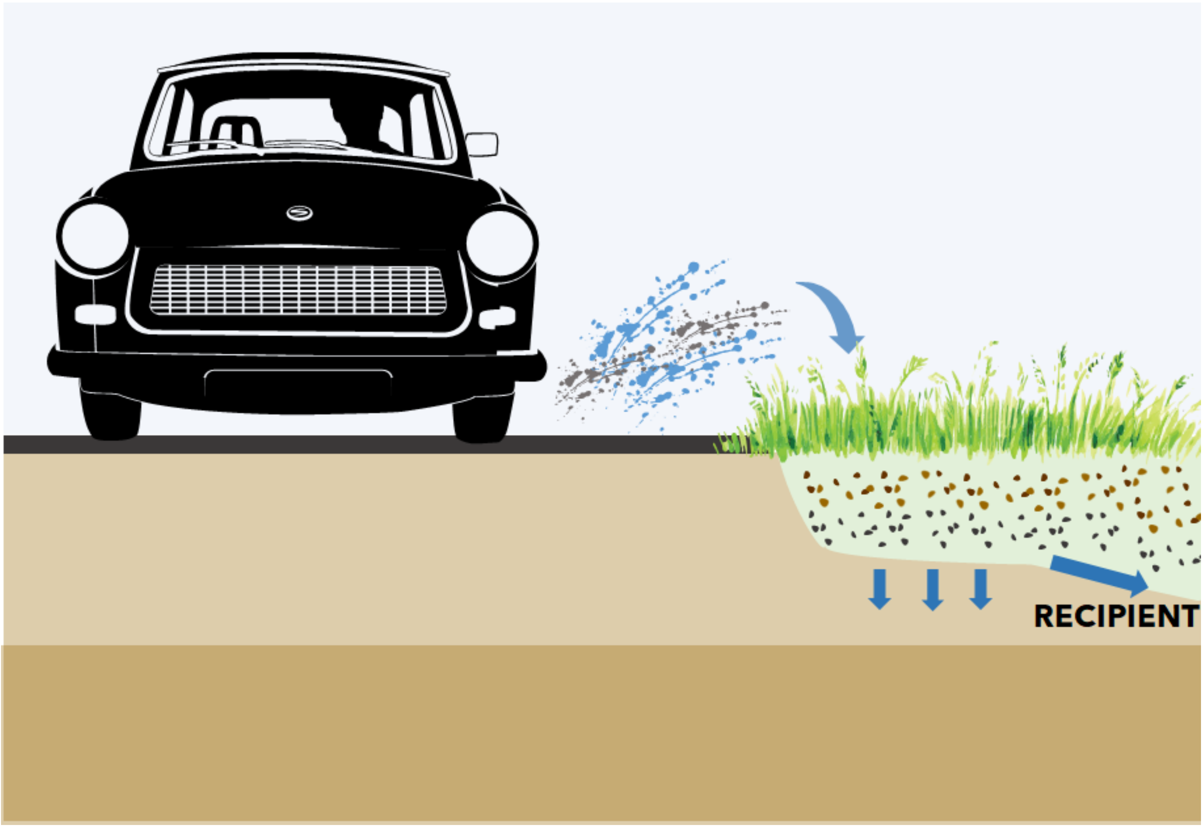

Figure 6. Conceptual illustration of a grass-filled swale (Illustration: E. Rødland, car and grass from freepik).

Road runoff treatment procedures

The handling of road runoff differs between different countries, from low levels of handling and treatment to more sophisticated capture and retention of contaminated road runoff. In order to combine knowledge and practices between the Scandinavian countries, the Swedish Transport Administration (STA), The Norwegian Public Roads Administration (NPRA) and the Danish Road Directorate (DRD) conducted a joint research project on treatment of road runoff, "Reducing Highway Runoff Pollution" (REHIRUP). A report published by the project (Andersson et al., 2018) summarizes the different approaches to road runoff treatment in Sweden and Norway and compares it to other European countries such as Germany and Switzerland. Denmark, Finland and Iceland were not covered in this report. The report also gives an overview of some of the most important documents that describes the handling and treatment of road pollution in Sweden and Norway (Table 2).

According to Andersson et al. (2018), road runoff in Sweden is commonly infiltrated in the road shoulder, embankments and open trenches, and the runoff is only treated when infiltration is not possible or prohibited. This approach represents **Pathway 3**, where the runoff can flow into the sides of the road. There are no national guidelines as to when or where road runoff should be treated. Demands for treatment of runoff in Sweden are usually set by municipalities and county boards, and these are based on site-specific conditions, such as the environment, hydraulic conditions, costs, aesthetics, and AADT (Anderson et al., 2018). Sweden has a guidance document (Vägdagvatten – Råd och rekommendationer för val av miljöåtgärd, Trafikverket 2011), describing the level of contaminants expected from road runoff for different AADT and suggested treatments.

In Norway, the handbook N200 (NPRA, 2018) specifies when a road (not including tunnels) must have water treatment measures for runoff, as illustrated in Pathway 4. In N200, all roads with > 30 000 AADT, require implementation of water treatment, with a minimum of two treatment steps (Table 1). For roads with AADT 3000 - 30 000 AADT, water treatment is required if the recipient water body has medium or high vulnerability. Determination of the vulnerability of a recipient is described detail in Ranneklev et al. (2016). For roads with >15 000 AADT and high vulnerability of the recipient, a two-step treatment is also demanded. The N200 also describes and defines these treatment steps. Step 1 is based on retaining particle-bound contaminants. This includes "natural" open sedimentation ponds, infiltration or a technical, closed treatment basin. Step 2 is based on retaining the dissolved contaminants and is applied after step 1. The second step includes another infiltration solution, for example a raingarden (Figure 7) or a filtration step in a closed facility. N200 also states that grass-filled swales and different types of infiltration solutions might retain road-related microplastic particles such as car tires, road paint and asphalt.

Table 1. Risk of impact on biodiversity in recipients and the need for treatment measures. Modified and translated from Norwegian (N200)

AADT	Impact on biodiversity	Need for treatment measures
<3 000	Low probability of impact in the recipient.	No treatment needed. Runoff is released into the roadsides and may be infiltrated in the surrounding areas.
3 000 – 30 000	Medium to high probability of impact in the recipient. Vulnerability of the recipient (low, medium, high) determines the measures required	Treatment measures shall be implemented if the recipient has high or medium vulnerability. If the vulnerability is high and the AADT is > 15 000, the measures shall include a two-step treatment.
>30 000	High probability of impact on biodiversity.	Treatment measures shall be implemented for all recipients (marine and freshwater). Measures shall at least include two-step treatments.

Figure 7. Example of a raingarden, applied as a second treatment step of tunnel wash water for the Smestad tunnel in Oslo, Norway (Photo: E. Rødland)

In Norway, water treatment for tunnel wash water is described in the handbook N500 (NPRA, 2020b). N500 only describes tunnel wash water in general, and there is no specific mention of microplastic particles or TWP. In N500, it is stated that the tunnel should be cleaned regularly, such that there is no need to treat the tunnel wash water. Further, N500 states that if the tunnel wash water is considered hazardous or possibly hazardous to the environment, a permit should be sought from the environmental authorities. If the permit demands that the tunnel wash water is treated before release, the minimum treatment should be sedimentation of particles, degradation of soap and separation of oil. These treatments should be in a closed facility. The description of how to clean a tunnel is included in R610 (NPRA, 2014).

Table 2. Overview over some of the documents that describes the handling and treatment of road pollution in Sweden and Norway.

Country	Publisher	Publication	Number	Reference	Year
Norway	NPRA	Handbook	N200	Handbook N200 for building roads	2018
		Handbook	N500	Handbook N500 for road tunnels	2020
		Handbook	R760	Handbook R760 Control of road building projects	2014
		Handbook	R610	Handbook R610 Standard for maintenance of roads	2012
		Publication	597-2016	Water reservoir vulnerability to road runoff during building and operational phases (NORWAT project)	2016
		Publication	212-2013	State of stormwater facilities in Norway	2013
		Publication	650-2016	Inventories of stormwater facilities in the South Region	2016
Sweden	STA	Requirement	2014:0045	Drainage – technical requirements for drainage	2014
		Handbook	2013:135	Surface and ground water protection	2013
		Handbook	2015:147	Open stormwater treatment plants – Inspection and Maintenance	2015
		Recommendation	2011:112	Stormwater – advice and recommendations for environmental action plans	2011
		Recommendation	2014:0046	Drainage	2014
		Recommendation	2014:0051	Drainage – Design and dimensioning	2014
		Publication	2003:188	Stormwater ponds – Investigation of function and efficiency	2003
		Publication	2006:115	Stormwater ponds – Sampling, sedimentation and hydraulics	2006
		Publication	2008:30:00	Maintenance of open stormwater treatment plants	2008

Water treatment facilities

In addition to gully-pots, some roads also have a treatment basin where road runoff enters after being collected through the gully-pots or by infiltration through a grass-filled swale (**Pathway 4**).

The NEA has especially mentioned the importance of tunnels as “hot-spots” for microplastic particles (NEA, 2019a). They suggest that as the tunnel wash water is collected, treatment of this water before release might be an efficient and cost-effective method of reducing the input of microplastic particles to the environment. They further state that tunnel wash water is usually treated in sedimentation ponds or basins. However, this statement is not a valid statement for road tunnels in Norway, considering that Norway has more than 1200 tunnels and only 377 treatment basins are currently in place along state and county roads in total, and only a few of those are built for tunnel wash water treatment (data retrieved from www.vegkart.no run by the NPRA).

Vegkart (www.vegkart.no) gives an overview of all facilities built along state and county roads in Norway. There are several types of water treatment basins listed (Figure 8, Table 3). The efficiency of the different basins as is not stated and may differ. Most basins are built for road runoff, and not for tunnels, even though tunnels are considered a hot-spot for road-related pollution (Grung et al., 2017; Hallberg et al., 2014; Meland & Rødland, 2018; Roseth & Meland, 2006; Åstebøl et al., 2011). Norway has in total 1229 tunnels registered in Vegkart, with more under construction and planning. There is no collective overview of how many of these 1229 tunnels have basins, but with the total of 377 basins registered (excluding the infiltration and wetland, which is typically related to runoff), it is likely that less than 30% of the tunnels have treatment facilities in place for the tunnel wash water before releasing it into a recipient. As many of the tunnels in Norway are built to bind together islands and fjord areas, a large proportion of these tunnels will have marine recipients. Details about the recipients to which the treated water is released are not listed in *Vegkart*. It was not possible to provide such detail within the scope of this project. With the use of Vegkart it can be determined, however, if the recipient was freshwater or marine by the distance from the basin to a possible marine recipient. In some cases, the road runoff is released to a nearby small stream which feeds into a larger marine recipient. For this purpose, this is classed as a marine release. This exercise showed that about 90 out of the 377 basins registered in *Vegkart* probably have a marine recipient. Some locations, especially tunnels, also have more than one type of basin associated with them, for instance sedimentation basins as pre-treatment before a larger treatment basin. Therefore the 377 basins may in fact be a low estimate as some of these basins are in fact linked to several roads or tunnel outlets. There are also a low number of permits for discharge of tunnel runoff registered (www.norskeutslipp.no), compared to the number of tunnels that exists. A total of 93 permits for road tunnels is registered, both for temporary and permanent discharges from tunnels, all related to roads. Some of these permits do include more than one tunnel, as the permit may be for road stretches rather than specific tunnels.

Figure 8. Overview of water treatment basins listed in the Norwegian road map application *Vegkart* (www.vegkart.no). Not all are shown on the map due to the scale. Markings: Water treatment basin (blue), Retention basin (yellow), Collection of pollution (red), Sedimentation (light green), Infiltration (dark green), Wetland (pink).

Table 3. Summarized information from the Norwegian road map application www.vegkart.no on the object "Basin" with these six functions attached: treatment, retention, collection of pollution, sedimentation, infiltration and wetland.

Type of basin	Number of basins	Possible outlet to marine recipients
Water treatment basin	145	25 (17 %)
Water treatment basin, Retention basin	53	13 (25 %)
Water treatment basin, Collection of pollution	81	26 (32 %)
Water treatment basin, Sedimentation	83	26 (31 %)
Water treatment basin, Infiltration	9	0
Water treatment basin, Wetland	6	0
Total	377	90

In Sweden, the road authorities have a map application similar to Vegkart, called *Stigfinnaren*[30]. This application also gives an overview of the number of water treatment basins built in Sweden. According to STA, however, there have been some issues with this application due to outdated information and

[30] https://www.trafikverket.se/tjanster/system-och-verktyg/Prognos--och-analysverktyg/aquavia/

it will therefore not be included in this report. According to a report for REHIRUP (Andersson et al., 2018), STA operates around 800 runoff treatment facilities and about 75% of these are sedimentation ponds. The Swedish Environmental Agency has funded several projects for the period 2020-2023 for measures against microplastic and other contaminants in runoff from urban and industrial areas (approximately 83 million SEK). These projects hopefully will produce new knowledge on which types of measures can retain microplastic from runoff.

Over 2 000 water treatment basins are built along the state road network in Denmark. Most of these are closed sedimentation basins (Grauert et al., 2011). A study of seven urban runoff ponds in Denmark, including one for highway runoff, found microplastic particles present in the stormwater that is discharged from the ponds to the environment (Liu et al., 2019). The study did not, however, include tire particles. The ponds made for highway and residential areas had the lowest concentration of microplastic, and the ponds in industrial areas had the largest. The study showed that the design of runoff treatment facilities greatly affects the retention of microplastic particles, and these stormwater retention ponds may not retain all types of microplastic particles.

In Finland, the few water treatment basins that exist are mainly for the road construction phase and not for operating roads. Only 10 road tunnels exist, according to their road map application (https://liikennetilanne.tmfg.fi). Contrary to their neighbours, the Finnish Transport Infrastructure Agency (FTIA) states that they do not have any specific implementation of increased road and tunnel cleaning in order to remove road runoff in general or microplastic. In Iceland, the road authorities did not respond to our request for information on their work with road runoff and microplastic. However, the Environment Agency of Iceland (EAI) informed us that Reykjavik city has decided to incorporate a strategy for urban sustainable drainage systems, in which retaining microplastic and other contaminants from urban runoff is included (ALTA, 2016).

In 2013, 26 randomly chosen water treatment basins in Norway were investigated and only 5 of these basins were classified to have "good" water treatment ability (NPRA, 2013). A comparable study was done for the water treatment basins in the southern region of Norway in 2016 (Gregersen et al., 2016). Out of 61 basins, only 21 of these were classified to have "good" water treatment ability. According to these reports, it is crucial for the efficiency for the water treatment measures that they are built to accommodate the volumes of contaminated water they will be receiving, built according to plans and managed according to plans. In many cases, sediments build up over time to the point where the basin no longer functions. Many of these have been upgraded to improve functioning. We do not have any reports showing how many of them are under operation and how many have been upgraded. These studies show that the current status of all the different water treatment basins currently in place in Norway is not known, and it is possible that some of these do not function optimally.

The Conference of European Directors of Roads (CEDR) is a European network of road authorities, which funds various road-related research projects. One of these projects is *MicropRoOf – Micropollutants in Road Run-Off water*[31]. One of the work packages measured tire particles in Sweden, Germany and the Netherlands (Dröge & Tromp, 2019). The results from this report suggest that tire particles can settle in smaller road wells and that the tire particle concentration in grass-filled side areas (swales) decreases with distance to the road.

[31] *https://www.cedr.eu/strategic-plan-tasks/research/call-2016/call-2016-water-quality/*

3.2.3 Wastewater treatment

In Sweden, the practice of combined sewage systems for both road runoff and sewage ended in the 1950s (Andersson-Sköld et al., 2020). A few percent of the road runoff in Sweden still goes to these WWTP (SEPA, 2016; Stahre, 2004). For Swedish municipalities, 8% of road runoff in urban areas is treated and the remaining 92% goes into a recipient without any treatment (SEPA, 2016).

In Norway, there is no overview of the percentage of road runoff entering combined sewage systems or reaching WWTPs (**Pathway 5**). The overall strategy is to have separated systems for stormwater and sewage, due to the risk of overflow during heavy rainfall (NOU 2015:16). The NEA states that combined systems are common in many Norwegian cities today (NEA, 2019a). This is not an ideal situation as most of these combined sewage systems do not have the capacity to transport and treat both road runoff and sewage, especially under more frequent episodes of heavy rainfall due to climate change.

The NEA states that upgrading the WWTPs to treat road runoff is not considered an effective solution, as both information on the amount of microplastic particles in road runoff and how effective these WWTPs are in retaining them is lacking. The retention of microplastic particles in general, however, has been assessed in studies of wastewater treatment plants (WWTP). Comparing these studies is difficult both because there are few such studies and because they represent different types of treatments. Nevertheless, they represent the current available knowledge on how microplastic particles may be retained in WWTP. Retention of particles >20µm was between 80 and 99% for Swedish WWTP (Ljung et al., 2018; Magnusson & Wahlberg, 2014), and 95 to 99% of all microplastic particles for Norwegian WWTPs (Magnusson, 2014). A collaborative study of WWTPs in Sweden, Finland and Iceland refers to the term microlitter, which is microsized litter items that are a result of human activities (Magnusson et al., 2016). These can be made of plastic, glass, wood or other material. The study reported the retention of microlitter particles >300 µm in several WWTP in the three countries. In Sweden and Finland, the reported retention from the WWTP was >99.7%. In Iceland, the study showed little or no retention at all. The major difference between the WWTPs is that in Iceland only one sedimentation step was used followed by a 3-mm filtration before discharging the wastewater (Figure 9). In Sweden and Finland, the treatment plants in the study also had sedimentation to remove particles, as well as both chemical and biological treatment steps. This shows that the retention of particles in WWTP is dependent on the type of treatment. On Iceland, the EAI informed us that there is a change underway in the regulations on urban wastewater, and stricter requirements for sewage treatment will be included. The Icelandic government is financing upgrades in local wastewater treatment over the next ten years. Studies from other countries have reported retention of microplastic in WWTP of 93 to 99.9% (Carr et al., 2016; Horton et al., 2017; Mintenig et al., 2014).

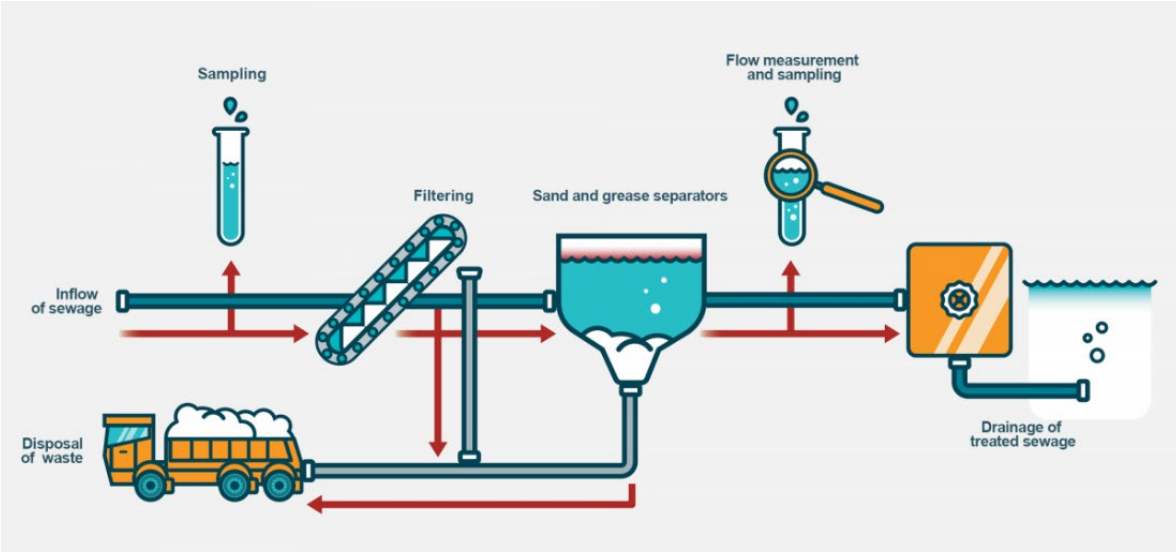

Figure 9. Schematic illustration of WWTP in Iceland (https://www.veitur.is/en/wastewater)

Up until now, no studies on microplastic particles in WWTP have specifically identified tire particles in either sediments or surface water samples (Bänsch-Baltruschat et al., 2020; Kole et al., 2017). A recent study on a WWTP in Oslo, Norway (Vogelsang et al., 2020) measured tire particles using Pyrolysis GC-MS. Here the WWTP was monitored for one year, and based on analyzed samples the study estimated that approximately 10 tonnes of car tire particles entered this WWTP per year. No tire particles were detected in the discharged water, which indicates that this WWTP was quite effective in retaining tire particles. According to the study of Mintenig et al. (2014), all microplastic particles with densities >1.2 g/cm3 should be retained in sewage sludge or sand traps (Bänsch-Baltruschat et al., 2020). As the density of tire particles is on average approximately 1.7-2.1 g/cm3 (Kayhanian et al., 2003; Snilsberg, 2008), it is likely that tire particles are also retained in the WWTP, mainly in the sludge. In order to assess the efficiency of tire particle removal in WWTPs, analytical methods targeting tire particles need to be applied. According to Hurley and Nizzetto (2018) about 50% of all sewage sludge from WWTP is recycled and used as agricultural fertilizers in Europe and North America (Nizzetto et al., 2016). Thus, the potential of a second pathway from farmland to marine recipients also exists through agricultural runoffs and should be addressed.

3.2.4 Requirements and standardized methods

In Norway, the Pollution Control Act (Forurensningsloven) aims to protect the environment against pollution and reduce existing pollution. The Pollution Control Act only applies for pollution from roads to the extent decided by the pollution control authority (article 5), which is the County Governor (Fylkesmannen). The Act states, however, that if there is risk of pollution, measures to stop or remove this pollution should be implemented (article 7). The pollution control authority may upon application issue a permit to any activity that causes pollution (article 11). The NPRA states that activities in both the building of roads and the maintenance of roads that cause significant pollution should apply for a permit from the County Governor. The NPRA stated in their interview that some projects have in recent years been met with requirements to include microplastic particles in their risk assessment when applying for a release permit for tunnel wash water where the AADT is considered to be high. Currently there is no information on how to assess the risk of the presence of microplastic particles in tunnel wash water or what concentrations of microplastic can be expected from tunnels.

The County Governor in Oslo and Viken has expressed (personal communication) that there is a need for guidance on how to set requirements for microplastic particles in permits. In many cases, requirements for measuring and monitoring the release of microplastic from road-related activities such as tunnel washing or snow deposits can be valuable inputs to the current knowledge gap on the quantity of microplastic and tire particles released. For this to be possible, standardized analytical methods need to be in place and available. The NEA (2019a) has stated that limits for microplastic in road runoff would only be considered where the runoff is either collected and discharged to the sewage system or directly to a recipient. They do, however, also state that it is difficult to set a limit with the current lack of knowledge on the effects of microplastic to the environment, as well as the lack of standardized methods of analytical measurements. This also applies for road related microplastic. For snow, the NEA also states that there is a need to establish guidelines for snow deposits and snow removal in order to have a uniform evaluation of all snow deposits. As described above, there are already differences in the requirements set in the permits for snow deposits between the various County Governors.

As shown here, there are a few studies that report measurements of tire particles in road samples, and there is a rapid development in this field. There are several research groups currently working on this issue, including Aquateam COWI, Chalmers University and NIVA (questionnare NPRA), as well as ongoing research at VTI (Trafikverket interview, personal communication with VTI). There is, however, still a need to direct attention to this matter.

3.3 Europe: status and experiences

Although the issue of microplastic from tire wear has gained attention in Europe, we found little evidence of implemented measures addressing the issue. This is likely because it gained attention in recent years, and there are still knowledge gaps that should be addressed in order to understand which measures should be implemented.

A recent expert workshop hosted by OECD and WBCSD (2020) discussed mitigation measures and policy options. Fostering research and encouraging knowledge sharing were considered important priorities, recognizing the need to address knowledge gaps with regards to sources and drivers of emission, fate and impacts on environments, as well as research on potential mitigation measures. At the EU level, the issue was addressed in the plastic strategy from 2018[32]. Vuola et al. (2019) gave an overview over existing policies and research in EU countries relevant for microplastic from tire wear among other, but did not focus on best practices or experiences *per se*.

3.3.1 Reducing microplastic emissions from tire wear

At the EU level work is underway to enable the introduction of tire wear rates in tire labels (section 3.1.1). In the Netherlands, potential measures have been assessed regarding the pollution reduction potential (Verschoor et al., 2016; Verschoor & de Valk, 2018) and associated costs and benefits (Vreeker et al., 2018, in Dutch). Specifically, Verschoor & de Valk (2018) assessed measures relating to tire wear rates as indicator in tire labels, legal thresholds for tire wear, choice of surface layers for roads, restrictions on winter tires in summer conditions, TPMS, maximum speed limit, and kilometer taxation. Based on the reduction potential as well as considerations for practical feasibility, environment and safety of suggested measures, IenW[33] selected three measures for an in-depth

[32] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A28%3AFIN

[33] Ministerie van Infrastructuur en Waterstaat (IenW), i.e. the Dutch Ministry of Infrastructure and Water Management

analysis of associated costs and benefits commissioned to Vreeker et al. (2018): adopting tire wear rates as indicator in tire labels, legal thresholds for tire wear, and promoting TPMS for cars registered before 2014. Vreeker et al. (2018) analysed the cost and benefits. Their results are only provided in Dutch. No evidence was found regarding whether any of these measures have yet been implemented. As mentioned above (section 3.1.1), work is underway at the EU level to develop a standardized wear test which is crucial to implement labels or legal thresholds based on tire wear rates. Thus, any adoption of these measures likely depends on related developments at EU level.

As mentioned in chapter 3.1, efforts targeting particle-related pollution to bring down local air pollution levels may also reduce emissions of microplastic, because they target the same source – tire and road wear particles. Some efforts against GHG emissions from road transport can deteriorate TWP emissions rates (i.e., electrification of vehicle fleet), while other efforts can improve the situation (i.e., efforts promoting other means of transport). Obligations at the EU or international level, such as the EU Ambient Air Quality Directive or Paris Agreement, suggest that European countries have implemented related measures which may help bring down TWP emissions. According to a briefing from the European Environment Agency (EEA, 2018), the transport sector was the main cause of exceedances of PM_{10} limit values. EU countries reported having implemented policy measures encouraging less-polluting transport modes, improving urban planning to support sustainable transport, and improving public transport, among others (EEA, 2018). These measures may be relevant for microplastic from TWP as well. Detailed assessment of best practices in Europe with regard to these strategies falls beyond the scope of our project.

3.3.2 Capturing emitted microplastic from tire wear

Measures against road pollution and road runoff is of interest not only in Norway and Sweden, but also in other European countries such as Germany, Switzerland and Austria (Andersson et al., 2018).
These countries have, however, managed road runoff in different ways. In both Sweden and Norway, the water quality has the highest focus and the measures that are incorporated are focused on retention capacity, aesthetics and ecology, whereas in Germany, Switzerland and Austria the focus is mainly on particle transport from roads (Andersson et al., 2018). For instance, in Germany, the road authorities use the expected annual load of particles (SS, suspended solids) smaller than 63 µm to determine the need for water treatment. Only when the expected load is >280 kg/ha per year are water treatment measures required (DWA, 2016, cited in Andersson et al., 2018). The size of TWP have been assessed using both road simulators and from environmental samples and found to be between a few nanometers and up to 5mm (Wagner et al., 2018). Based on the studies of Kreider et al. (2010) and Smolders and Degryse (2002), however, it is expected that most TWPs will be in the size range 65-80 µm. Thus, treatment measures that target the SS may be a strategic approach to retain both TWP and other road-related particles. It is as yet not possible to specify the annual discharge limit of these particles, as there is little information available on the relationship between SS and TWP. We do, however, recommend that this is an approach that the Nordic countries should address and discuss with other road authorities.

4 Recommendations

Recommendations for measures to reduce the emission of microplastic from tire wear:

- Strategies to reduce microplastic emissions from tire wear should be **seen in relation to work in other policy areas such as local air quality, climate, environment and public health,** as these can co-benefits from such measures. Nordic countries should consider implications for other policy areas as well when assessing costs and benefits of implementing measures against microplastic from tire wear, and vice versa.
- Work is underway at EU and international level to establish standardized measurement methods for emissions from brakes and tires. The standard is crucial to implement tire wear as factor in tire labels and regulations. **Relevant authorities in Nordic countries should follow this process,** and possibly contribute with their expertise and concerns where appropriate (e.g., regarding studded tires).
- EU regulations ensure that tire pressure and wheel alignment are controlled in periodic vehicle inspections. Moreover, mandatory tire pressure monitoring system for new cars (from 2014) ensures optimal tire pressure between inspections. However, a study from the Netherlands showed that implementing such systems in older cars accounted for most of the reduction potential. Therefore, **Nordic countries could assess whether adopting regulations for older cars as well would be cost-effective**.
- Recent studies found that negative impacts on human health of particle emissions (to air) from studded tires outweigh the benefits of using studded tires. Reducing the use of studded tires will also reduce emissions to other pathways, thus ease the work of capturing emitted particles. Taxation has influenced consumers' choice of winter tires (studded vs. non-studded) in Norway. We recommend **the Nordic countries to consider recent results and assess whether they should adopt other policies (e.g. taxation) to address pollution from studded tires.**

Recommendations for measures to capture emitted microplastic particles from tire wear:

- There is an urgent need to **establish a standardized analytical method for quantifying tire particles in environmental samples**. At the moment there are several research groups working on different methods and several have published their findings. To be able to compare results across studies, it is important that standardized methods are used and that these methods are validated. Standardization is an area that both the road authorities and the environmental authorities need to address together with the research community.
- With a standardized method in place, it is necessary to **increase the knowledge on the mass flow of tire particles in the environment**. Tire particles should be included in monitoring of contaminants in runoff, both from roads, tunnels and urban areas and in projects investigating the retention of tire particles in different environmental compartments such as the grass-filled swales, freshwater sediments and surface water, and marine sediments and surface water. An increased knowledge on concentrations from different parts of the transport pathway will provide better insight into the mass balance of tire particles in different areas. This will likely have local and national variations.
- Present knowledge on tire particles, microplastic particles and road pollution in general, suggests that a large fraction particle-related pollution will be retained in any treatment that

has sufficient capacity for sedimentation of the runoff. This includes different types of water treatment basins for road and tunnel water and it includes WWTP. Gully-pots can probably retain some fraction of the larger tire particles, if they are maintained regularly and kept at 50 % capacity. However, there is a need for **more research on the efficiency of retention for alternative designs of these water treatments**, so that future applications can choose the most optimal design to capture microplastic particles.

- The **environmental authorities and the County Governor need to have updated knowledge on this matter** in order to set the correct requirements for discharge permits and implementation of water treatment for road and tunnel runoff. The road authorities also need to have updated knowledge in order to evaluate runoff from roads and tunnels and to apply for permits for the discharges.

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