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Indicators for microplastic flows

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SMED (Swedish Environmental Emissions Data), is a collaboration between IVL Swedish Environmental Research Institute, Statistics Sweden (SCB), Swedish University of Agricultural Sciences (SLU) and the Swedish Meteorological and Hydrological Institute (SMHI). The collaboration commenced in 2001 with the long-term aim of gathering and developing the competence in Sweden within emission statistics. SMED is, on behalf of the Swedish Environmental Protection Agency and the Swedish Agency for Marine and Water Management, heavily involved in the work related to Sweden's international reporting obligations on emissions within six subject areas (air, water, waste, hazardous substances, noise and measures). Environmental statistics is also produced for national and regional needs, where SMED compiles data for both milestone targets and environmental quality objectives. SMED also develops new methods and produces statistics for follow-up of Sweden's National Waste Plan and Waste Prevention Program. For more information, visit the SMED website www.smed.se (in Swedish)

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Summary

SMED is short for Swedish Environmental Emissions Data, which is a collaboration between IVL Swedish Environmental Research Institute, Statistics Sweden (SCB), Swedish University of Agricultural Sciences (SLU), and Swedish Meteorological and Hydrological Institute (SMHI).

To reduce the leakage of plastic into nature the Swedish Environmental Protection Agency (Swedish EPA) has established two indicators for follow-up: "Littering of objects containing plastic" and "Estimated total leakage of microplastics in Sweden". The aim of this project was to propose detailed indicators for prioritised sources and pathways that may be used to annually follow-up the spread of microplastics in Sweden.

This has been done through expert workshops, interviews, literature studies, and in close dialog with Swedish EPA. The following aspects were considered for the proposed indicators: data availability, representativeness, possible sampling- and analytical methods, as well as calculation approaches, method uncertainties and its cost-efficiency.

Based on these results, the following indicators are suggested to be used to follow-up leakage of microplastics from the sources and pathways prioritised by Swedish EPA:

Tyre wear - Microplastics from tyre wear (kg/y) based on national annual traffic activity data (vehicle km) for different vehicle classes. The annual traffic activity data is multiplied with vehicle class-specific emission factors (g/km) to calculate the total leakage.

Artificial grass pitches (AGP) - 1) Replenishment of infill on Swedish AGP:s based on an annual survey where facility owners report actual replenished infill (kg/m^2). To scale up the amount (kg/y) of replenished infill to national level, an estimate of the total area of AGP:s with rubber infill could be estimated based on available statistics. 2) A certification system for AGP:s in Sweden is introduced to provide well-managed pitches. The certification should assure that the facility owners have made certain measures to reduce emissions of microplastics. The indicator to follow-up is the number of certified artificial grass pitches.

Industrial production of plastic pellets - Introduced reporting requirement of microplastics emissions for all Swedish producers of plastic pellets based on sampling and analyses being performed in effluent water. Data on microplastics leakage (kg/y) can be made available through changes of relevant permits or via new legislation.

Architectural and antifouling paint - Weight of polymers in architectural paint, antifouling paint and other hull paint put on the Swedish market annually (kg/y) are considered to reflect the amount of microplastics spread to nature from paint.

Littering – Total annual amount (kg/y) of plastic litter based on the annual national plastic litter monitoring program to be introduced 2023 and/or the existing urban litter monitoring program run by The Keep Sweden Tidy Foundation (HSR). Macrolitter is considered to reflect the leakage of microplastics to nature.

Wastewater – 1) Measured average load of microplastics (g/pe, y) in wastewater treatment plants, both incoming and effluent water. This can be conducted through an extension of the existing Swedish EPA's Environmental Toxics Coordination's sub-programme on environmental toxins in the urban environment, analysing occurrences of chemicals in effluent water from sewage treatment plants, to also include microplastics. By analysing the water for total amount of microplastics as well as fractions such as rubber particles and textile fibres, the results can also be used as an indicator for the source "laundry" and the pathway "stormwater". 2) Reported average volume (m^3/pe, y) of sanitary sewer overflow at WWTP and from the sewer systems in Sweden based on existing environmental reporting. 3) Measured average load of microplastics (g/pe, y) in WWTP sludge based on the same monitoring program as indicator 1).

Wind – Measured average yearly deposition (g/m^2, y) of microplastics in bulk deposition analysed based on volume proportional monthly samples in the existing the Swedish Throughfall Monitoring Network.

Since the suggested indicators are mainly based on existing data and monitoring programmes it should be possible to run development projects for suggested indicators in 2023, aiming for full implementation by 2024.

When several indicators are proposed, they are prioritized in number order.

It has not been possible for the project to quantify a cost for suggested indicator system. However, mostly existing and yearly available data is utilised in the proposed indicators. Due to this, it is considered that the suggestions can be implemented without high costs for facility owners and authorities.

Keywords: microplastic, indicator

Sammanfattning

För att minska läckaget av plast till naturen har Naturvårdsverket infört två indikatorer för uppföljning av detta mål: ”Nedskräpning av föremål som innehåller plast” och ”Uppskattat totalt läckage av mikroplast i Sverige”. Syftet med detta projekt var att föreslå detaljerade indikatorer för prioriterade källor och transportvägar som kan användas för att årligen följa upp spridningen av mikroplast i Sverige.

Detta har skett genom expertworkshops, intervjuer, litteraturstudier och i nära dialog med Naturvårdsverket. Följande indikatoraspekter har beaktats: datatillgänglighet, representativitet, provtagnings- och analysmetoder, beräkningsmetoder, metodosäkerhet och kostnadseffektivitet.

Baserat på dessa resultat föreslog projektet följande indikatorer som syftar till att följa upp läckage av mikroplast från de källor och transportvägar som prioriterats av Naturvårdsverket, se Tabell 1.

Tabell 1: Sammanfattning av förslagna indikatorer, metodbeskrivning samt omfattningen av förslagen för de prioriterade källor och spridningsvägar som studerats i denna studie.

Källa	Indikator	Metod	Omfattning
Däckslitage	Total mängd mikroplaster från däckslitage utifrån årliga trafikaktivitetsdata och emissionsfaktorer (kg/år).	Årliga trafikaktivitetsdata (fordonskilometer) för olika fordonsklasser multipliceras med fordonsklasspecifika emissionsfaktorer (g/km). Kostnaden för denna indikator förväntas vara medelhög till hög beroende på hur ofta emissionsfaktorerna uppdateras.	Trafikaktivitetsdata täcker hela vägnätet i Sverige. Svenska emissionsfaktorer för personbilar och lastbilar kommer snart att finnas tillgängliga. Extrapolering behövs för andra fordonstyper.
Konstgräsplaner	1. Återfyllnad av svenska konstgräsplaner med gummigranulat (kg/m^2, år).	Metoden är baserad på enkät som skickas till anläggningsägare för att uppskatta mängden återfyllnad per m^2. För att skala upp mängden infill till nationell nivå kan en extrapolering utifrån total yta konstgräsplaner användas. Osäkerheten i uppskalningen är dock omfattande, då spridningen varierar mycket mellan planerna, främst pga skötsel.	Den föreslagna indikatorn beskriver bara mängden återfyllnad med gummigranulat. Uppskattningen ska inte betraktas som den faktiska spridningen av mikroplast till naturen, men den ger ändå värdefull information om hur konstgräsplanerna sköts och därmed en indikation på spridningen av mikroplaster från dem.

	2. Certifieringssystem för svenska konstgräsplaner (antal certifierade planer).	Ett certifieringssystem införs för att säkerställa välskötta konstgräsplaner och som visar att anläggningsägarna har vidtagit definierade åtgärder för att minska utsläppen av mikroplast, men även för att säkerställa långsiktigt god funktion.	Detta system skulle innebära att vissa åtgärder krävs (säker snö och dagvattenhantering, mm) och ett minimikrav på utbildning av personalen som sköter planerna. Indikatorn ger ingen direkt information om mikroplastspridningen, men ger information om åtgärder införda för att minska denna.
Industriell produktion av plastpellets	Infört rapporteringskrav på mikroplastutsläpp för svenska producenter av plastpellets (kg/år).	Metoden avser analyser som görs på utgående vatten från Inovyn AB och Borealis AB i Stenungsund. För detta behöver krav införas på Borealis AB att rapportera utsläpp av mikroplast. Data kan tillgängliggöras genom ändrat tillstånd eller via ny lagstiftning på EU-nivå. Kostnaden för denna indikator förväntas bli medelhög eftersom nya analyser behöver genomföras, men befintliga provtagningsprogram kan användas.	Indikatorn är avsedd att täcka nationella utsläpp, då det bara finns två aktiva anläggningar som producerar plastpellets. Endast utsläpp av mikroplast via process- och dagvatten på fabriksområdet beaktas med denna indikator.
Fasad- och båtbottenfärg	Vikt polymer i fasad- och båtbottenfärg som släpps ut på den svenska marknaden (kg/år)	För varje kategori av färgprodukt kan årliga siffror över volym färg och vikten polymer i denna som släpps ut på den svenska marknaden sammanställas. Information lämnas av tillverkare och importörer av färg genom sin årliga produktregistrering till Svenska Produktregistret vid Kemikalieinspektionen. Den totala vikten polymer i färg antas avspegla mängden mikroplast som potentiellt kan spridas i naturen. Kostnaden för denna indikator beräknas vara låg, då den är baserad på fritt tillgängliga data.	De uppgifter som redovisas till Svenska Produktregistret omfattar i allmänhet produkter som importeras eller tillverkas över 100 kg/år. Sammansättningsdata är allmänt tillgängliga för ingredienser som klassificeras som hälso- eller miljöfarliga och som finns i en koncentration på eller över 5 %. De sammanställda uppgifterna förväntas representera de totala volymer som släpps ut på den svenska marknaden varje år.

Nedskräpning	Årlig mängd plastskräp (kg/person, år).	Uppskattningar baserade på det årliga nationella övervakningsprogrammet för plastskräp som ska införas 2023 och/eller det befintliga skräpmätningsprogrammet som drivs av stiftelsen Håll Sverige Rent (HSR). Låg kostnad för denna indikator förväntas eftersom data är tillgängliga från befintliga eller planerade övervakningsprogram.	Indikatorn är avsedd att avspegla nationella urbana utsläpp av mikroplast från plastskräp till naturen. Det finns dock inga etablerade samband (emissionsfaktorer) mellan makroplast och mikroplast. Dessutom är tidsaspekten hur länge skräpet ligger kvar betydelsefull för hur mycket mikroplast som bildas.
Avloppsvatten	1. Uppmätt medelbelastning av mikroplaster (g/pe, y) i avloppsrenings-verkens inkommande- och utgående vatten.	Kvantifiering av mikroplast från avloppsvatten genom utökning av Naturvårdsverkets befintliga miljöövervakningsprogram ”Miljögifter i urban miljö” där förekomster av kemikalier i slam och utgående vatten från avloppsreningsverk följs årligen till att även omfatta mikroplast.	Indikatorerna är avsedda att spegla nationell spridning av mikroplaster via avloppsvatten från reningsverk, bräddavlopp och slam.
	2.Rapporterad genomsnittlig volym (m^3/pe, y) bräddvatten vid reningsverket och från avloppssystemet.	Genom att analysera inte bara totala mikroplaster utan även fraktionen textilfibrer kan resultaten också användas som indikator för källan "tvätt".	
	3.Uppmätt medelbelastning av mikroplast (g/pe, y) i avloppsslam.	Medelkostnad för denna indikator förväntas då befintliga övervakningsprogram används men nya analyser krävs.	
Dagvatten	Uppmätt medelbelastning av gummipartiklar i avloppsreningsverkens inkommande vatten (g/pe, år).	Kvantifiering av mikroplast från avloppsvatten genom utökning av Naturvårdsverkets befintliga miljöövervakningsprogram ”Miljögifter i urban miljö” där förekomster av kemikalier i slam och utgående vatten från avloppsreningsverk följs årligen till att även omfatta gummipartiklar i inkommande avloppsvatten, för tätorter i övervakningsprogrammet som har kombinerade ledningsnät, där delar av dagvattnet avleds till reningsverk. Medelkostnad uppskattas för denna indikator, då befintliga övervakningsprogram används men nya analyser krävs	Den föreslagna indikatorn kan användas för att se förändringar mellan år, men kan inte extrapoleras nationellt, eftersom de lokala förhållandena för dagvatten varierar kraftigt. Osäkerheter också stor då mellanårsvariation i flöde kan vara omfattande, vilket påverkar resultatet.
Vind	Uppmätt genomsnittlig årlig deposition av mikroplast i totaldeposition (g/m^2, y).	Uppmätt årlig medelkoncentration av mikroplaster i totaldeposition analyserad baserat på volymproportionella månatliga prover i det befintliga Svenska Krondroppsnätet.	Depositionen av mikroplaster kan skalas upp till hela Sverige men speglar då bara bakgrundsituationen,

			då deposition i tätort kan vara betydligt högre och mer varierande.

Eftersom de föreslagna indikatorerna för uppföljning av läckage av mikroplaster till naturen huvudsakligen baseras på befintliga data och övervakningsprogram bör det vara möjligt att driva utvecklingsprojekt för föreslagna indikatorer 2023, med sikte på fullt genomförande 2024.

Om flera indikatorer föreslås är de prioriterade i nummerordning.

Det har inte varit möjligt för projektet att kvantifiera en kostnad för föreslagna indikatorer. Men då indikatorerna till mestadels baseras på befintliga och årligt tillgängliga data bedömer projektet att detta system kan implementeras utan höga kostnader för anläggningsägare och myndigheter.

Introduction

The Swedish Environmental Protection Agency (Swedish EPA) has developed a roadmap for sustainable plastic use with four different impact areas defined: *Resource-smart usage*, *Significantly increased and high-quality material recycling*, *Raw materials and production with minimal environmental impact* and *Reduced plastic leakage into nature*[1]. Each of these impact areas has a number of indicators for follow-up.

To reduce the leakage of plastic into nature, the following indicators have been established:

- Littering of objects containing plastic (weight/year, broken down by product category).
- Estimated total leakage of microplastics in Sweden (weight/year, broken down by source and transport routes).

Swedish EPA wants in collaboration with Swedish Environmental Emissions Data (SMED) develop proposals for how the follow-up of the indicators concerning littering of objects containing plastic and microplastics should be done, i.e., how the estimate of total leakage of microplastics in Sweden (weight/year, broken down by source and transport routes) could be implemented in practice. If weight/year-indicators are not feasible SMED will suggest indicative indicators that can be used to follow-up policy measures to reduce the leakage of plastic into nature.

The follow-up indicators are based on the main sources and transport routes defined in Swedish EPA's government assignments "Microplastics-Reporting of government assignments on sources of microplastics and proposals for measures to reduce emissions in Sweden" (Swedish EPA, 2017) and "Microplastics in the Environment 2019" (Swedish EPA, 2019). The proposals should take into account differences between sources and transport routes. In addition, they could deal with recurring sampling in suitable matrices with linked flow measurements, possible development of necessary source tracking and perhaps combined with modelling and/or material flow analyses. A general cost estimates to implement the proposals should be presented for each of the proposals.

SMHI shall, together with Swedish EPA, work for better knowledge and national monitoring of the spread of microplastics[2]. SMHI will develop existing tools to include the spread of plastic via waters. The tool must be able to be used to assess the risk of releases of microplastics from different

[1] The Swedish EPA's roadmap for the sustainable use of plastics (naturvardsverket.se)
[2] https://www.esv.se/statsliggaren/regleringsbrev/?rbid=22268

areas and map release sources. The assignment must be reported to the Government Office (Department of the Environment) no later than 15 December 2023.

Aim and scope of the study

The project aims to propose indicators that may be used to regularly follow-up of the spread of microplastics in Sweden. The proposals intend to enable the total leakage of microplastics to the environment in Sweden (weight/year, broken down by source and distribution route) to be estimated. Furthermore, proposed methods intend to provide information about the effect different measures and policy developments have had on the leakage of microplastics into the environment over time. The proposals focus on the main sources and transport routes defined in the Swedish EPA's government mandate.

Definition of microplastics

Microplastics are defined by the Swedish EPA as solid particles of plastic and rubber regardless of shape (for example as grains, flakes, and fibres), which are between 1 nm and 5 mm in their largest dimension, and which are insoluble in water. Synthetic fibres with a length between 3 nm and 15 mm and a length to diameter ratio >3 is also included in this concept. Swedish EPA in principle follows European Chemicals Agency’s definition for microplastics (ECHA, 2022), with the addition of including biodegradable plastics in this concept.

Included sources and pathways of microplastics

In 2016, IVL Swedish Environmental Research Institute (IVL) on commission by the Swedish EPA estimated losses of microplastics for identified sources and pathways (Magnusson et al., 2016). Swedish EPA subsequently carried out a study in dialogue with relevant authorities and other stakeholder based on the IVL report with the aim to define the most important sources of microplastics in Sweden and analyse possible measures to reduce the spread of microplastics (Swedish EPA, 2017). A linked governmental assignment presented by Swedish EPA in 2019 included the same sources and pathways (Swedish EPA, 2019).

The included sources and pathways in this study are primarily based on these reports, as well as iterative consultations with Swedish EPA during the project. In Table 1 the most important sources of microplastics in Sweden are briefly described.

Table 1: Sources of microplastics as well as pathways included in this study based on information by Magnusson et al. (2016) unless otherwise stated.

Source/pathway	Description
SOURCE	
Road wear and abrasion of tyres	Road traffic is estimated as the largest source of microplastic in Sweden. Emissions are primarily due to wear and tear of vehicle tyres, and secondly due to wear and tear of road surfaces and markings. About 8 190 tonnes of microplastics are released from abrasion of roads and tyres per year. There are, however, major uncertainties in the calculation methods used (Andersson-Sköld et al., 2020a).
Artificial grass pitches	The spread of microplastics from artificial grass pitches (AGPs) has been identified as one of the main sources of microplastic emissions in Sweden. Due to weather and wind as well as activities such as snow removal, infill and synthetic fibres of grass are spread to the environment. Approximately 475 tonnes of microplastics are released from AGPs each year (Swedish EPA, 2019).
Industrial production and handling of plastic pellets	Material losses from industries that manufacture plastic or plastic products have been identified as one of the sources of microplastic emissions in Sweden. Material losses of plastic pellets can occur as point emissions to water and air from plants that manufacture pellets or plants that use pellets as inputs. Material losses can also occur as diffuse emissions in connection to loading and transportation of plastic pellets. Approximately 310–530 tonnes of

	microplastics are released from industrial production and handling of plastics pellets each year.
Laundry of synthetic textiles	All textiles, regardless of fibre and material, wear and tear during use and washing, which leads to the release of microparticles in the form of small fibres from the textiles. In the case of textiles made from synthetic materials, this means that plastic microfibres released when washed ends up in the wastewater. It was estimated that 8–950 tonnes/year of microplastics are released from laundry of synthetic textiles in Swedish households. A later study estimated releases of microplastics from industrial laundries in Sweden to be 2,2-115 tonnes/year (Swedish EPA, 2019).
Antifouling paint	Some antifouling paints (paint used to prevent growth on ship hulls etc) contain polymers as binders. Some of these polymers are believed to form microplastic particles when the surface of the boat gradually wears out or when the boat is washed, scraped or sanded during maintenance. The emissions of microplastics from antifouling paint was estimated to 160–740 tonnes of microplastics per year. However, continued estimates of emissions of microplastics from antifouling paint have shown that the emission volumes are probably significantly lower, about 10 tonnes of microplastics per year (Swedish EPA, 2017). It is however still an important source to address, as the emissions are linked to hazardous substances, and that the emissions occur directly into water.
Architectural paint	The recent published report "Plastic Paints the Environment" indicate that plastic architectural paints is a major source of microplastics (Paruta et al., 2022).There are however yet no quantifications available of microplastics from architectural paint.
Littering	Littering contributes to plastic ending up in the ocean, which eventually breaks down into microplastics. The fragmentation of plastic can take a long time, up to several hundred years. Globally, plastic litter is considered to be the largest source of microplastics in the ocean (Swedish EPA, 2017). Emissions of microplastics from littering in Sweden has not been estimated, but is expected substantial, perhaps even the largest source of microplastics. National littering monitoring in Sweden has been carried out by the Keep Sweden Tidy Foundation where it was estimated that 3.3 million plastic items were thrown away in all of Sweden's 290 municipal central areas in total. The weight of the plastic items was estimated at 8 tonnes (Swedish EPA, 2020a).
PATHWAYS	
Wastewater	The largest mapped sources of microplastics entering the treatment plants originate from textile laundry and hygiene products, which contribute between 67-927 tons of microplastics per year, and where the larger proportion comes from textile laundry. In combined sewer systems microplastics from stormwater is also an important source.

Stormwater	Stormwater serve as a dispersal route for microplastics and other pollutants to seas, lakes and streams. Sources of microplastics in stormwater can be, for example, road and tyre wear, artificial grass pitches (AGPs), industrial production and management of primary plastics, surface treatment and painting of buildings, and littering (Swedish EPA, 2017).
Wind	Microplastics particles are transported by air to areas far away from sources. In 14 deposition studies conducted outdoors concentrations range from 1,600 to 11,000 particles m−2 d−1. The substantial difference in deposition depends partly on different methodologies for sampling, processing protocols an analysis (Prata et al., 2022). Deposition of plastic fibres, plastic fragments and tyre wear particles (TWP) were detected at most deposition sampling locations also in a Swedish study (Magnusson et al., 2020a).

Methodology

The project consisted of the following activities and corresponding methods. During the course of work, prioritised sources and pathways, data availability and proposed methods were coordinated and discussed with the Swedish EPA, see Table 2.

Table 2: Overview of the included activities and methods utilised in the project.

<table>
<tr><th>Number</th><th>Activity</th><th>Method</th></tr>
<tr><td>1</td><td>Determine prerequisites for the indicator including what counts as sources and pathways including definition of system boundaries and recipient.</td><td>Literature study, kick-off meeting and ongoing dialogue with Swedish EPA and SMHI.

Coordination with Swedish EPA of proposed priority of sources.</td></tr>
<tr><td>2</td><td>Overview description of data availability to follow up the largest sources of microplastics as well as the transport routes. Propose prioritisation of these sources and transport routes based on data availability and the roadmap for sustainable plastic use.</td><td>Expert workshops, interviews, literature study.

Coordination with Swedish EPA of proposed methods.</td></tr>
<tr><td>3</td><td>Propose one or several indicators for each selected source and route. Possible methods are, for example, measurements, material flow analyses, modelling, sales statistics, etc. Aspects to consider are:
a. Data availability (not only that the data exists, but also that it can be accessible in a long-term perspective).
b. Representativeness (indicator data should be scalable to the entire country).
c. Possible sampling- and analytical method, as well as calculation and viable modelling approaches need to be defined for each source/pathway.
d. Uncertainties for the methodology and the possibility of ensuring a significant change over time.</td><td>Expert workshops, interviews, literature study.

Coordination with Swedish EPA of proposed methods.</td></tr>
<tr><td>4</td><td>Cost estimate of the proposed methodology for each source and transport route and assessment of the information value.</td><td>Estimates.</td></tr>
</table>

The costs associated with the proposed indicators were estimated based on a system where the indicator was categorised as contributing to *low*, *medium,* or *high* costs.

- *Low costs* – Refers to an indicator that is based on already available data, thus, not requiring further collection of data. However, costs for compiling data or non-comprehensive calculations may occur.
- *Medium costs* – Refers to an indicator that requires complementary data to estimate releases of microplastics of that source or pathway. Costs of compiling and calculations may occur.
- *High costs* – Refers to an indicator that requires extensive collection of new data. In addition, costs associated to large fundamental changes of e.g., the utilised machinery or analysis equipment, a company's permit or other similar changes may be required.

Sources of microplastics

In this chapter, proposed indicators for estimating emissions of microplastics from the included sources are presented. The sources are presented in the following order:

- Road wear and abrasion of tyres
- Artificial grass pitches
- Industrial production and handling of plastic pellets
- Laundry of synthetic textiles
- Antifouling and architectural paint
- Littering

Road wear and abrasion of tyres

Tyre wear from road traffic is regarded as the largest source of microplastic emissions in Sweden accounting for about 7 674 (tonnes/year) (Magnusson et al., 2016). Abrasion of road markings and road wear (polymer modified bitumen) also contributes to the overall microplastic leakage from road traffic. However, the contribution from these sources is estimated to be smaller than tyre wear. According to estimations by (Magnusson et al., 2016), around 6 tonnes of microplastics from road wear and 504 (tonnes) from road markings was released yearly in Sweden. The total release from road traffic is thus estimated 8 190 (tonnes/year).

Road markings

Road markings (RM) contain fillers, additives, pigment and resins and the polymeric resins can end up in the environment and contribute to microplastics (Andersson-Sköld et al., 2020b; Tomasz E. Burghardt et al., n.d.). RM materials have been identified to constitute a smaller source of microplastic emissions, compared to e.g., tyre wear, and the polymer content in the materials is low. The share of paint-related plastic pollution has been estimated to 2% of the global emissions of all microplastics (Paruta et al., 2022). According to the producers of road markings in Norway, the binding agent constitutes 20% of the total road marking mass. However, the polymeric mass in the binding agent is only 2% (Rødland Støhle, 2022). Furthermore, out of the paint identified as RM paint that was put on the Swedish market during 2021, the percentage of rosin/petroleum resin/wax estimated to constitute around 98% of the total mass of polymer/rosin[3].

[3] The Swedish Product Register at KemI (the Swedish Chemical Agency). Email conversation October to November 2022.

The abrasion of road markings is affected by many factors such as the composition and characteristics of the RM material, the location on the road, the traffic load, the traffic conditions, the extent of studded tyres, weather conditions and ploughing (Andersson-Sköld et al., 2020).

The leakage of RM paint has either been assumed to fully reflected the annual consumption (Sundt et al., 2014) or estimated from the annual consumption in combination with abrasion factors, based on parameters such as the degree of reapplication (Lassen et al., 2015). Releases of microplastics has then been calculated from the chemical composition of the RM material. Using this approach as an indicator for the follow-up of microplastic release in Sweden seems to be associated with several issues and uncertainties.

The Swedish Transport Association is responsible for maintenance of the state road network, but the re-application work performed is strictly correlated to budget frameworks and does not well reflect the actual demand[4] (Johannesson & Lithner, 2021). Municipal and private road keepers are responsible for the maintenance of the rest of the Swedish road network[5] and no statistical data or information on maintenance work from these actors have been found. An uncertainty with estimating the amount of RM that is actually abraded before re-paint (Johannesson and Lithner, 2021), has therefore been identified.

The Swedish Product Register administered by the Swedish Chemicals Agency (KemI) provided information about the amount of road marking paint put on the Swedish market each year. RM paint can be expected to be reported to the product register in either of the application categories "Other (e.g., furniture-, artist-, means of transport- and road paint)" or "Road paving materials". Further filtration is then made. The reported products can be divided into different categories, however, there will be cases where products have not been reported[6].

One thing that is important to consider is that different RM materials are designed with different functions. Depending on the function (type of RM material) the release of microplastics may vary broadly. Thermoplastic RM materials can be expected to contribute more to the release of microplastics than other RM products. These RM paints are developed to continuously provide retro-reflective properties after abrasion, in contrast to other RM materials which fully rely on the drop-on layer of glass beads. This means

[4] The Swedish Transport Administration. Email November 2022.
[5] https://www.trafikverket.se/resa-och-trafik/underhall/sa-skotervi-vagar/
[6] The Swedish Product Register at KemI (the Swedish Chemical Agency). Email October to November 2022.

that these RM materials are renewed with a fresh layer of base as well as a drop-on layer of glass beads before the significant part of the paint is abraded (Burghardt et al., 2022). Information on how much of the re-paint work that can be related to those RM materials has not been found.

There is little knowledge about the relative loss of microplastics from different road marking products and there are no standardised methods for calculating emission factors (Burghardt et al., 2022; Hann et al., 2018). As a result of above-mentioned issues and lack of a suitable approach, no indicator could be proposed for road marking materials. This is mainly due to uncertainties about the actual release of polymer-containing RM materials and the complexity of characteristics of different materials.

Abrasion of asphalt containing polymer modified bitumen (PMB)

Some types of asphalt contain polymer modified bitumen (PMB) which contribute to the release of microplastics during road wear. PBM is rarely used in the wearing courses, the topmost layer of the pavement, in Sweden (Järlskog, 2022). The Swedish Transportation Administration estimated that around 8% of the total amount of asphalt applied on the state road network in 2021 was made up of PMB[7]. Some factors affecting the wear of the surface of the road is the characteristics of the road, the type of material, how it was applied, climate conditions, the use of studded tyres and the traffic volume (Andersson-Sköld et al., 2020b). However, little is known about the release of microplastics related to PMB (Johannesson and Lithner, 2021).

As aforementioned, the Swedish Transport Administration as well as municipals and private owners of roads are responsible for the maintenance of the Swedish road network. No statistical information on maintenance work by municipals or private road keepers have been found in this study. Furthermore, not all maintenance work is intended to repair worn road surfaces. The work also includes e.g., crack filling, pothole repair, surface strengthening, or even out deformations resulting from heavy traffic[8]. Another uncertainty would be that around 50% of the PMB lies underneath the wearing course of the road surface and will not be subjected to the same degree of wear (Swedish EPA, 2017).

Based on this information and a lack of suitable approach and data sources, no indicator could be proposed for road ware of PMB.

[7] The Swedish Transport Administration. Email November 2022.
[8] The Swedish Transport Administration. Email November 2022.

Tyre wear

Tyre tread consists of 40-60% rubber (elastomer) of both natural rubber (polyisoprene) and synthetic rubber (mainly polybutadiene and stirene-butadiene-rubber) (Järlskog, 2022; Rødland Støhle, 2022). Except rubber, tyre tread is also made up of fillers, plasticizing agents, chemicals for vulcanization, softening and anti-aging agents, as well as other additives (Järlskog, 2022). It has been debated whether tyre wear particles (TWP) should be regarded as microplastics. However, since the particles contain polymeric rubber, these particles are often included in the definition of microplastics in research studies within the field (Järlskog, 2022) and in policy work aimed at reducing the leakage of microplastics (European Commission, 2022a).

The amount of tyre wear generated is affected by several factors such as the properties of the tyres, the properties of the vehicle and the characteristics of the road surface. Other factors are e.g., climate conditions and driving behaviour (Andersson-Sköld et al., 2020b; Johannesson et al., 2021; Mennekes and Nowack, 2022). In a study by Ye Liu et al. (2022), measurements on tyre wear were conducted on the left-front and left-rear tyres of taxis. It was found that the type and position of the tyres (rear or front) have a larger impact on tyre wear than driving behaviour. Although, among behaviour-related abrasion factors speed changes e.g., acceleration and braking has been found to be related to high abrasion (Järlskog, 2022; Ye Liu et al., 2022).

Estimations of releases of tyre wear particles are often based on theoretical calculations (Järlskog et al., 2022). Mennekes & Nowack (2022) showed that estimations of TWP generally have been oversimplified. Very few studies have based their estimations on actual measurements. The calculations in most studies instead relied on other reviews or summarizing studies. Few studies had performed own measurements and out of those several originated from the 1970s (Mennekes and Nowack, 2022). Furthermore, there are no acknowledged or standardized methods of estimating emissions of tyre wear particles or emission factors. In addition, existing modelling approaches do not account for local differences (e.g., landscape, vehicles and road characteristics) (LEON-T, n.d.).

Estimations of emissions of tyre wear have generally been made by utilizing one out of two approaches. The first approach is based on different emission factors in combination with traffic activity data (Andersson-Sköld et al., 2020b; Hann et al., 2018; Swedish EPA, 2017). The second approach is a material flow analysis (MFA) based on quantities and qualities of sold or recycled tyres in combination with an End-of-Life (EOL) wear factor (the average percentage weight loss during service life) (Andersson-Sköld et al., 2020b; Wagner et al., 2018). The derived estimated emissions of TWP have then been multiplied with an estimated content of rubber in tyre tread.

In an ongoing project funded by the European Union's Horizon 2020 research and innovation program a new emission model based on tyre wear data obtained from laboratory and on-road experiments will be developed. The model will be used for further estimations of the environmental fate of tyre wear particles, providing information on effective measures to reduce the emissions[9].

Proposed indicator

Microplastics released from TWP emissions based on traffic activity data

The proposed method for estimating releases of microplastic from tyre wear relies on country specific emission factors in combination with traffic activity data. The annual traffic activity data (vehicle km) of different vehicle classes (passenger cars, goods vehicles, buses, motorcycles) are multiplied with vehicle class specific emission factors (g/km) to provide estimations on the TWP emissions produced each year. According to the definition of microplastic particles used in this project the whole TWP is regarded as microplastic. . The following equation is used for the calculations:

$$\sum E_{MP_i} = TA_i * EF_i$$

Where:

E_{MP_i} = Total emissions of MP from tyre type *i*

TA_i = Total traffic activity (km), for vehicle type *i*

EF_i = Emission factor for vehicle type *i* (Swedish conditions) (g/km)

Removal- and preventive methods for decreasing microplastics from tyre wear were discussed by e.g., Johannesson & Lithner (2021) and Winquist et al. (2021) see Table 3. Winquist et al. argue that removal methods are costly, and that it is difficult to remove MP from the environment. They further discuss that preventive methods are cost-effective and do often not depend on further technology development. Effects of the described preventive measures is expected to be covered by the proposed indicator.

Table 3: Examples of preventive and removal methods for reducing the emissions of tyre wear to the environment as earlier discussed in literature.

[9] Leon-T project (2022, 10 December) https://www.leont-project.eu/

Reference	Preventive methods	Removal methods
(Johannesson and Lithner, 2021)	• Reduced traffic activity • Changed driving behaviour • Development of tyres with higher resistance to wear • Optimization of air pressure and wheel settings	• Collection of tyre particles while driving • Sustainable handling of road surface water • Knowledge building for the assessment of risks and need for action
(Winquist et al., 2021)	• Proper use of tyres (e.g., pressure, wheel alignment) • Driving behaviour • Tyre characteristics (non-studded, studded etc.)	• Treatment solutions for stormwater • Treatment of urban dust and snow

Data availability

Estimations of emissions of tyre wear particles require data on traffic activity and emission factors. These data sources are available and presented below.

Traffic activity data

Traffic activity data covering the whole Swedish road network is provided by Transport Analysis as a part of the Swedish official statistic. The data is available online and disaggregated into different vehicle types i.e., passenger cars, goods vehicles (> 3.5 ton and < 3.5 ton), buses and motorcycles.

The data is updated annually and are calculated from odometer readings collected during inspection, hence covering the whole Swedish road network. It is based on the Swedish Transport Agency’s register on Swedish-registered road vehicles and include all vehicles that have been in traffic for at least one day during the reference year. The odometer readings are inspected, and adjustments are made for incorrect values. However, some incorrect odometer readings cannot be adjusted and those will be provided with model estimates. The same applies for vehicles that do not have a reported mileage e.g., vehicles that have been newly registered, are directly imported or deregistered. Vehicles provided with model estimates make up between 20% - 50% of all vehicles. The model suggests that the distance driven for one day is the same for all the days the vehicle has been in traffic during the reference year (Transport Analysis, 2012). The current estimation model (mean value imputation) used for vehicles that do not have a reported mileage during the reference year will be updated and a new model (regression model) is expected to be in place in 2023. Incentives for the update have been to increase the accuracy and flexibility for incorporating new types of e.g., fuels. The update is although not expected to affect the traffic activity data, compared to present model[10] (Transport Analysis, 2022).

Another available data set is annual average daily traffic (AADT) data for the state road networks in different regions, counties and municipalities which is available on the Swedish Transport Administration´s official webpage[11]. The data are provided from measurements carried out during a four-year cycle on the main road network (European roads, national roads, and primary county roads) and during a twelve-year cycle on other state road networks. The state road network makes up 98 500 kilometres and municipal roads covers 42 800 kilometres in 2019 (Johannesson and Lithner, 2021). According to the Swedish Transport Administration, the Swedish road network in 2017 consisted of: 98,500 km of state roads and 42,300 km of municipal streets and roads. 74,000 km of private roads with state subsidies. However, the largest part of all traffic work is carried out on the state and municipal road network, together these constitutes the public road network (Andersson, 2014). No similar data has been found for the municipal or private road network. The Swedish National Road and Transport Research Institute (VTI) developed a model for estimating the total traffic work in Sweden based on AADT. The calculations are based on the traffic work on the state road network which is then multiplied by a factor 1.48 to provide the total traffic work on public roads (Andersson, 2014).

From the available data found on traffic activity in Sweden, the data provided by Transport Analysis is proposed as an indicator. The data covers the whole Swedish road network, are updated annually, and are associated with relatively low uncertainties and costs.

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[10] Statistics Sweden (SCB). Interview October 19, 2022
[11] The Swedish Transport Administration (2023, 10 December) https://bransch.trafikverket.se/tjanster/trafiktjanster/Vagtrafik--och-hastighetsdata/fordonsfloden-och-hastigheter/

Traffic activity data provided by Transport analysis is also expected to be continuously provided. The new estimation model is not expected to affect the total results[12] (Transport Analysis, 2022). These data are therefore considered to have good permanency over time. However, the same situation does not apply for TWP emission factors and continuous update of these factors should therefore be assured, while new types of vehicles, mainly electric, and tyre development will affect the amount of TWP generated.

Emission factors

TWP emission factors (EF) define the amount of TWP generated per kilometre driving distance (mg/km) (Wagner et al., 2018). The EF is-based on several factors related to the properties of the tyres, the properties of the vehicle characteristics, characteristics of the road surface, and driving behaviour (Wagner et al., 2018). The calculations of released microplastics are highly dependent on information of rubber content and the provided EF as estimates may differ greatly depending on this value (Agewall and Wallgren, 2019).

The TWP EFs is generally determined from measuring the weight loss of the tyres after driving a certain distance, or by measuring the difference in profile depth (Mennekes and Nowack, 2022). In a recent investigation performed by Allgemeiner Deutscher Automobil-Club (ADAC) emission factors for a passenger car in western Europe has been suggested to be about 100 – 120 (mg/km per vehicle). Measurements were then made directly at the tyres, measuring tyre tread depth with a laser measuring device under realistic driving conditions in Germany (ADAC, 2022). The study was suggested as one of the most trustful recent studies determining EFs, by Mennekes & Nowak (2022). Nevertheless, newer EFs for other vehicle types could not be found. Such values are necessary for providing more precise TWP estimations.

Country-specific emission factors for passenger cars and trucks in Sweden is expected to be determined in the ongoing LEON-T project, which will be finished in approximately one year (LEON-T, n.d.). LEON-T will suggest measures that are effective and widely accepted by investigating particulate emissions from tyres and propose practical standardised methods for both lab and road testing of tyre abrasion rate and airborne particulate emissions.

[12] Statistics Sweden (SCB). Interview October 19, 2022

System boundaries

Some vehicles are not included in the traffic activity statistics from Transport Analysis, e.g., trailers, mopeds, and camper vans. The data is not delimited to vehicle-kilometers driven in Sweden but also includes traffic work abroad.

Recipient

Since the indicator is based on calculation models rather than actual measured occurrence of TWP in specific environmental matrixes, the recipient for this indicator is “the environment” outside the road surface.

Representativeness

Traffic activity data provided by Transport Analysis covers the whole Swedish road network. Despite the uncertainty of a potential imbalance between transit and internal vehicles this data can be regarded to well represent the traffic work performed in Sweden each year.

No information has been found about the quality of the Sweden-specific emission factors provided by the LEON-T project. However, these are believed to be suitable for this indicator. The emission factors to be provided however only represents passenger cars and trucks and it is not including trailers mopeds, and camper vans.

Uncertainties of the methodology

There are some uncertainties connected to the Traffic activity data that is available through Transport analysis. For example:

- The relation between non-Swedish-registered vehicles driving through Sweden, and Swedish-registered vehicles driving outside Sweden is unknown. This becomes more relevant the greater the imbalance between transit and internal traffic is. Investigating this further would provide better information about the uncertainties.
- A relatively large number of vehicles (20% - 50%) are provided with model estimated mileages which could involve some uncertainties. This is due to that passenger cars in Sweden, new or directly imported, are inspected the first time no later than 36 months after the vehicle was put into use, the second time no later than 24 months after the previous inspection and then no later than 14 months after the previous inspection.
- The inspection and evaluation of the validity of odometer readings and daily mileage may be inadequate because some misreading’s may not be discovered.

- Calculations on traffic work during a reference year are based on mileages performed both before and during the reference year. This means that the presented traffic work is a relatively rough material to use as a basis for some purposes e.g., to envisage effects of the economy on car usage. This should be considered if the data would serve as part of an indicator.
- Some vehicles are not included, e.g., trailers, mopeds, and camper vans.

There is no standardized method for estimating tyre wear emission. In addition, EFs are often old and generalized factors associated with great uncertainties. Especially since the large changes in the car fleet over the last 10 years (according to available data from Transport Analysis). The following is important to reduce the uncertified connected to EF:

- Swedish EFs for passenger cars and trucks is expected to be delivered in the LEON-T project. However, no up-to-date values for other vehicle types e.g., buses and motorcycles are available and for those some sort of extrapolation will be required. Furthermore, we have received little information about those EFs and how they will be determined.
- Even if country-specific average emission factors will be provided, the great variation of tyre abrasion between different tyres will still mean uncertainties.
- It is of great importance to ensure a continuous update of emission factors. Using outdated EFs would mean considerable uncertainties.

Another issue with the indicator is that consequences of policy measures which aim to target microplastic pollutions that are already released from its source, will not be detected with this indicator. However, changes related to tyre characteristics and reduced traffic work will be captured provided updated, qualitative information about the qualitative EFs.

Estimated costs

As traffic activity data is already provided by Transport Analysis the costs of the indicator mainly depend on the costs of providing updated EFs. The costs are as follows:

- Tests and measurements are expected to be required for the development of updated values of EF for different vehicle classes.
- Compilation of collected data, followed by further calculations.

Assuming EFs will be updated every third year the average annual costs is estimated as *high*.

Considered but not proposed indicator

Modelling microplastic emissions using material flow analysis (MFA)

Emissions of microplastics could be modelled using a material flow analysis (MFA). As earlier mentioned, the approach is based on quantities and qualities of sold or recycled tyres in combination with an End-of-Life (EOL) wear factor (the average percentage weight loss during service life) and information about re-treading of tyres for heavy duty vehicles (trucks and buses).

Calculating the TWP emissions based on the total mass of tyres put on the Swedish market each year would be according to:

$$E_{MP} = W_{T_{tot}} * WLF_i * RF_i$$

Where:

E_{MP} = Total emissions of MP

$W_{T_{tot}}$ = Total weight of tyres put on the Swedish market

WLF_i = Weight loss factor during the service life of tyre type i.

RF_i = Retreading factor (1 + average number of retreading for tyre type i)

Based on the weight of collected tyres, the calculation would be as follows:

$$E_{MP} = \frac{W_{EOL_{tot}}}{1 - WLF_i} * WLF_i * RF_i$$

Where:

E_{MP} = Total emissions of MP

$W_{EOL_{tot}}$ = Total weight of collected tyres at their EOL

WLF_i = Weight loss factor during the service life of tyre type i.

RF_i = Retreading factor (1 + average number of retreading for tyre type i)

Data availability

The following sources have been found for the required data.

Data on weight of collected tyres and sales statistics

Information on the number of tyres put on the Swedish market each year could possibly be provided by utilising relevant commodity codes (CN codes) for receiving information on national export and import volumes and combining this data with data on national production of tyres. The calculation method was e.g., used in a study conducted by Fråne et al. (2022) to estimate the amount of plastic put on the Swedish market in 2020. The number put on the market could potentially be estimated based on the following equation:

$$Put\ on\ the\ market\ (tonnes) = \ Imports + National\ production - Exports$$

The data is easily available at Statistics Sweden´s[13] website and can be provided annually. One issue related to this data is that some CN codes are presented as weight and not as numbers, which requires the data to be converted which entails further uncertainties. Data on the national production of tyres has not been further investigated. This means that there are some uncertainties associated with this method at this point.

SDAB (Svensk Däckåtervinning AB)[14] provides sales figures of tyres. These figures, however, only include tyres reported by importers that have paid their recycling fee and are connected to SDAB's system. Furthermore, the figures only include loose tyres and the number of tyres placed on the market as originally fitted on vehicles are unreported. SDAB collects most of the tyres in Sweden and annual information on the total weight of collected tyres are provided at their website. Retreaded tyres however are not included in the statistics as they are not considered as EOL tyres. Alongside the SDAB system, car manufacturers administer a separate system for collecting tyres, via BilRetur[15]. To obtain data on the total number of tyres collected in Sweden each year, statistics from both systems should be used. However, no data on the total weight of the EOL tyres collected by BilRetur was found.

It should be noted that depending on if there is a mild or harsh winter, the number of tyres collected each year may vary with thousands of tons. Furthermore, the number of collected tyres may also vary with hundreds of tons depending on whether the workshops schedule their pick-up before or after the last of December[16].

Weight loss factor

In earlier literature the weight loss of a tyre during its entire service life has been 10-40% considering a tyre life span of four years or up to 60 000 km. Depending on which value that is used, very different results may be

[13] Statistic Sweden (2023, 10 December) https://www.scb.se/en/
[14] SDAB (2023 10 December) https://www.sdab.se/
[15] Bilretur (2023 10 December) https://bilretur.se/
[16] Swedish SDAB. Personal communication in October – December 2022.

presented (Mennekes and Nowack, 2022). Available data are not up-to-date and does not specifically represent tyres in Sweden. No indications of upcoming or ongoing studies, or the development of such wear factors has been found.

Utilising country-specific weight loss factors would be highly preferable for an indicator estimating the losses of microplastics from tyre wear. Furthermore, it is important to work with up-to-date values since out-dated weight loss factors may result in misleading outcomes. For example, revised legal requirements such as requirement of a tread depth of a minimum of 3mm even during the summer period, would largely influence the weight loss factor. In addition, an increased number of tyres could be expected to be used on the Swedish market. Hence, the situation would be an increased number of sold or collected tyres in combination with an overestimated weight loss factor. This would provide overestimated amounts of tyre wear particles emissions, emphasizing the importance of updated weight loss factors.

Retreading

Retreading of tyres for heavy duty vehicles (buses and trucks) must be considered in the calculation, since it might influence the tyre wear. The prevalence of retreading has decreased over the last decade, and it is important to ensure continuous correct information. Some tyres used for heavy duty vehicles could be expected to be retreaded up to three times (during the service life), while others are not retreaded at all. No information on the average number of times the tyres are retreaded was found in this project.

System boundaries

Provided available data, the indicator would represent the weight loss of all types of tyres in Sweden.

Recipient

Since the indicator is based on calculation models rather than actual measured occurrence of microplastics in specific environmental matrixes, the recipient for this indicator is “the environment” outside the road surface.

Representativeness

The available data sources for the number of tyres put on the market as well as the collected EOL tyres do not represent the actual situation in Sweden that well. Both have significant limitations when used for an indicator as intended in this project. No weight loss factors representing Sweden-specific tyres have been found. The weight loss factors found in literature show highly variable values and are outdated.

Uncertainties of the methodology

The methodology and data on imports, exports, and national production of tyres in Sweden provides ambiguous estimations. Examples of such limitations and uncertainties are:

- Free riders in the reported and collected statistics.
- Significant simplifications of the calculations following the estimate of the tyres put on the market.
- CN codes are not always reported in numbers which.
- National production of tyres may not be available which affects the result of the method.

SDABs' data on collected tyres are also limited by some uncertainties. For example, the number of tyres connected to their system and tyres not connected to their system cannot be distinguished. This leads to the collection of an unknown number of tyres that are not connected to their system. In 2018, they estimated this amount to 7 000 – 8 000 tonnes of tyres but the amount has decreased since, mainly due to the implementation of the separate system administered by BilRetur. Today SDAB has no exact information about the number of free riders into their system but estimates around a 50% decrease during the last four years.17.

There are issues related to the use of this model approach as an indicator. The major challenge lies in finding representative updated weight loss factors for Sweden. The few data available provides rough estimations, not suitable for the purpose of the indicator. Except the weight loss the retreading factor of heavy-duty vehicles highly influence the calculated release levels of microplastics. However, provided available and continuously updated data (weight loss factors, collected or sold tyres, retreading) the method should be considered as a potential indicator.

Artificial grass pitches

Large amounts of microplastics are believed to be released to nature from the around 1 300 AGPs in Sweden each year (BEKOGR, 2018). Microplastics are released during use and maintenances of the pitches and originates mainly from the infill and the artificial grass fibres i.e., the blades

[17] Swedish SDAB. Personal communication in October - December 2022.

of the grass. There are various reasons to why infill is spread from AGPs, for example, snow removal and everyday maintenance of the pitches and from sticking to players' shoes and clothes. Some of the infill that is removed during snow removal is collected and returned to the AGPs or disposed of as waste (Swedish EPA, 2017).

Mainly two approaches have been identified in the literature to estimate the emissions of microplastics from AGPs in Sweden. The first assumes that the amount of replenished infill corresponds to the infill lost from the pitch. Based on this approach Swedish EPA estimated that approximately 475 tonnes of microplastics are released from AGPs each year (Swedish EPA, 2019). The second approach is based on material flow analysis used to develop emission factors for a number of sizes of AGPs, which is multiplied with the total number of pitches of a certain size in the country. Wallenberg et al. (2016) estimated utilising material flow analysis that around 630 – 1 264 tonnes of infill is released to the environment each year from AGPs in Sweden. Similar studies estimating the release of microplastics from AGPs has been conducted in, for example, Norway (Sundt et al., 2016, 2014), Denmark (Lassen et al., 2015) as well as on a European level (Hann et al., 2018).

These aforementioned approaches have inherent limitations and uncertainties in the results that need to be highlighted. Firstly, only infill is taken into account, not considering other losses such as artificial grass fibres. However, there is no widely approved method for calculating emissions from AGPs that includes all origins of microplastics. In addition, estimating the losses of infill based on replenished amounts has been identified to overestimate the emissions of microplastics as compaction of the infill mean that larger volumes must be added than has been lost (Magnusson et al. 2016). A study conducted by Fleming et al. (2015) shows that the compaction can be counteracted almost completely with sufficient maintenance. This view is shared by the Swedish Football Association[18].

AGPs are considered an environmentally hazardous facility and the Swedish EPA has developed a guidance intended for operators and supervisory authorities of AGPs. Anyone who owns or is responsible for the maintenance and upkeep of leisure and sports facilities where granules are used, for example an AGPs, is considered an operator. For example, a municipality or a football association can be an operator of an APG. The responsibility entails that measures are taken to prevent and reduce the environmental impacts.

[18] Swedish Football Association. Meeting 8th of December 2022.

In the government assignment published by the Swedish EPA in 2021, it was proposed that APGs should be covered by a notification requirement. This is considered to have great potential for reducing microplastic emissions from AGPs. This would entail that requirements on precautionary measures and specific requirements could be set based on APG's location. In addition, other adaptations can be made through requirements such as technological design, the choice of materials, maintenance, and waste management. The proposal specifies that all types of AGPs of at least 200 m^2 should be included in the notification requirement including e.g., playgrounds and sports grounds. A consequence of a requirement for notification is that it would lead to greater administrative costs for both the operators and the supervisory authorities.

AGPs have been identified as an important source of microplastics at the European level (ECHA, 2020a). A proposal from the European Commission has been presented to the Member States in the REACH Committee in 2022. The proposal relates to the amendment of *Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards synthetic polymer microparticles*. This includes several sources of microplastics such as AGPs. The proposal presents two methods for reducing emissions of infill from AGPs (European Commission, 2022b).

1. A total ban on putting plastic-based infills on the market intended for artificial turf pitches with a transitional period of six years without exemptions.
2. A ban on putting plastic-based infills on the market with the exception of use where risk management measurements have been implemented to ensure that annual microplastic emissions do not exceed 7 g/m^2. This includes a transitional period of three years.

Proposed indicator I

Replenishment of infill on Swedish football pitches

Replenishment of granules have been identified as a method for estimating emissions of microplastics. The proposed indicator includes a questionnaire being sent to several municipalities in Sweden asking for data regarding replenished infill. The amount and type of replenished infill will be estimated per m^2 based on the responses of the survey. With available data from The Swedish Football Association, the total area of artificial football pitches could be used to estimate the total losses of infill per year. This indicator should be seen as representing the maximum potential losses of infill to nature, not the actual losses. The amount of infill added to an APG should not be seen as only replacing the amount of infill spread to nature, while parts will also compact on the pitch, follow players or end up in waste disposal but used as a yearly indicator it can still provide valuable information about changes in management practices and plastic materials used impacting the spread of microplastics.

The survey may include questions such as:

- How many AFPs do you have of each of the most common sizes (11, 9, 7, 5 persons)?
- What type of infill is used on the AFPs? Including options such as Styrene Butadiene Rubber (SBR, virgin or recycled), ThermoPlastic Elastomer (TPE, virgin or recycled), Ethylene Propylene Diene Monomer rubber (EPDM, virgin or recycled), cork (expanded or unexpanded), olive seeds, sand with plastic coating or no infill.
- How much infill and what type of infill has been replenished on the AFP (kg) last year? Only infill intended for replenishment of lost infill should be included (actual refill and not purchased amount).

The selected municipalities covered by the indicator may potentially be limited to the members of The Artificial Grass Pre-procurement Purchasing Group (BEKOGR) as well as the Regional Development and Cooperation in the Environmental Target System (RUS) network of municipalities. BEKOGR enables collaboration between municipalities regarding AGPs. In addition, the organisation distributes funding for various types of feasibility studies, investigations, and tests, with the aim of increasing knowledge about the environmental impact of AGPs and how it can be minimized. RUS supports, guides, and coordinates the work of the county administrative boards and the Swedish Forest Agency in the environmental goal system.

Currently, BEKOGR sends out a questionnaire with similar questions to member municipalities. Since the start of their work, both the purchase of granules and refill have decreased[19]. Additionally, many of the municipalities linked to BEKOGR do not refill infill during the life of the AGPs.

Data availability

The data can potentially be made available through a collaboration with BEKOGR and RUS. However, relevant data is already available for BEKOGR's members as of now. Additional data about the number and size of APGs might be received from the Swedish football association.

[19] Holgersson, Pernilla. Coordinator at BEKOGR. Email 19th of September 2022.

According to BEKOGR, the organisation is to continue its work after the suspension of funding by the Swedish EPA from the last of December 2022. Instead, the organisation will be funded by its members during at least a three-year period[20]. However, there are no clear indication of what will happen with BEKOGR from 2026 and onwards. As of RUS, no indication has been found that the organisation or their network will change in the coming years.

System boundaries

The proposed method is limited to a selection of municipal and AGPs. Moreover, only losses of granular infill are included in this indicator as well as only artificial football pitches or similar APGs are considered.

Recipient

The considered recipient is the surrounding area outside of the AGPs. This includes both adjacent land and water areas.

Representativeness

There are about 20 municipalities that are members of BEKOGR, and RUS has a network of about 40 municipalities[21]. It was not possible to establish if there is an overlap between these networks. Data received from a survey sent out to both BEKOGR and RUS would represent, at the most, approximately 60 out of the 290 municipalities in Sweden. This corresponds to around 20% of the municipalities. The members of BEKOGR account for about 400[22] of the around 1 300 AGPs in Sweden (BEKOGR, 2018), about 30% of the total number of pitches. However, it should be taken into account that all contacted municipalities may not respond to the survey which would affect the representativeness of the results.

Scaling up the results at national level would contribute to uncertainties but is possible. Refill could be estimated per square meter based on the received answers. The Swedish Football Association can provide an estimate of the number of AGPs in Sweden. Based on this, the indicator could be used to estimate emissions at national level.

Uncertainties of the methodology

As there are limitations of this indicator that contributes to uncertainties. For example, the compaction factor of infill that occurs during the use of the

[20] Holgersson, Pernilla. Coordinator at BEKOGR. Email 19th of September 2022.
[21] Eriksson, Magnus & Bergstrand, Marie-Helene. Operations manager and employee of the RUS working group. Emails 23rd of September 2022.
[22] Holgersson, Pernilla. Coordinator at BEKOGR. Email 19th of September 2022.

AGPs. This indicator should be emphasized as representing the maximum emissions of infill to nearby nature instead of representing the overall losses of microplastics from AGPs. Another aspect is that other microplastic emissions arise from AGPs, such as artificial grass fibres. However, as already stated, no other method for estimating losses of artificial grass fibre has been found appropriate.

Furthermore, the margin of error of the estimate depends to a large extent on the number of municipalities that respond to the survey year to year. Large differences in the replenishment of infill can exist between different municipalities which impacts the results. Another impact on the representativeness of emissions may arise as BEKOGR's members who actively work with similar problems are asked. These municipalities are at the forefront of measures to reduce the environmental impact of AGPs, which can be misleading if these are to represent all of Sweden's municipalities.

Estimated costs

As relevant data is already collected via BEKOGR's and their members, additional costs associated with the proposal are as follows:

- Costs associated to developing a questionnaire that can be reused annually; however, BEKOGR might be able to provide useful insight and information regarding the questionnaire
- Administrative costs will arise for additional municipalities responding to the survey, for example the network connected to RUS
- Annual compilation of collected data and calculation of the indicator.

Based on the aforementioned costs, this indicator is assumed to be associated with *medium* costs as some complementary data may be collected in addition to the data provided by BEKOGR.

Proposed indicator II

Certification system for artificial football pitches in Sweden

There are multiple measures for reducing the losses of microplastics from AFP. According to the Swedish Football Association[23], a well-managed artificial football pitch can reduce the need for replenish infill completely. In addition, losses of infill and artificial grass fibres can also be reduced with measures such as protective fencing and stormwater filters. Results from a new AGP with SBR-infill in Kalmar indicate that with all suggested

[23] The Swedish Football Association. Meeting 8th of December 2023.

measures applied the spread of microplastics to the water environment can be limited to approximately 0,1 kg/year of which 10% deemed to be infill (Regnell, 2019). The Committee for Risk Assessment (RAC) however still has a clear preference for ban on placing rubber infill on the market over different restriction measures (ECHA, 2020b).

The proposed indicator is to introduce a new certification system for artificial football pitches that provides a well-managed field where certain minimum requirements have been met. The system should be developed in collaboration with e.g., the Swedish Football Association and interested municipalities. The requirements could potentially include:

- Approve maintenance plan implemented.
- Only certified maintenance personnel responsible for pitch upkeep.
- Necessary protective measures have been introduced (site specific).
- A yearly report is submitted to the certification body specifying results from the control program, including the amount of infill replenished.

An implemented certification system for AFP is expected to reduce the spread of microplastics substantially and at the same time extend lifetime of the pitches, maintain good playing conditions and be more cost efficient.

The suggested indicator is number of certified pitches in Sweden. This indicator is intended to be used in combination with the proposed indicator *Replenishment of infill on Swedish football pitches*.

Data Availability

No data is available at this point in time. However, The Swedish Football Association has shown interest in such a certification system.[24] Building a voluntary certifications system in dialog with relevant actors for AFP is expected to take about a year.

System boundaries

All artificial football pitches in Sweden would in time be able to get certified. However, the requirements that need to be met have not yet been specified.

Recipient

The recipient of microplastic from artificial football pitches is the environment outside the pitch not limited to the arena.

[24] The Swedish Football Association. Meeting 8th of December 2022.

Uncertainties of the method

There are several uncertainties connected to this method, for example:

- Even if an AFP has been certified, there is no guarantees that the pitch is managed in a way that it should. Independent system auditing and random controls of independent qualified organisation are important to make the system legitim.
- A voluntary system is not likely including the majority of Sweden´s AFP. Some pitches are owned by small clubs with limited resources to spend on certification if there are no strong obligations or economic incentives.

Estimated costs

The costs associated with this indicator is considered as *high* as a completely new certification system would have to be developed, but well implemented it can be cost efficient.

Industrial production and handling of plastic pellets

Material losses from industries that manufactures plastics pellets or plastic products have been identified as one of the sources of microplastic emissions in Sweden, estimated to 310 – 533 tonnes (Magnusson et al., 2016). During the manufacturing of plastic products, mainly virgin plastic is used, often in the form of plastic pellets. Material losses of plastic pellets can occur as point emissions to water and air, both from plants that manufacture pellets or plants that use pellets as inputs (Swedish EPA, 2017). Multiple attempts to estimate the losses of plastic pellets during production and handling has been conducted, for example studies by Cole & Sherrington (2016) and Sundt et al. (2014). The aforementioned studies developed emission factors based on available data to estimate the losses. However, different studies have come to different EFs when it comes to calculating the emissions of pellets.

OSPAR has developed Action 52: “Zero pellet loss in the manufacturing chain” to promote initiatives and exchange of best practice aiming at zero pellet loss along the whole plastics manufacturing chain from production to transport (OSPAR, 2022).

In 2020, the Swedish EPA published guidelines with measures to minimise the release of microplastic from manufacturing and handling of plastic pellets (Swedish EPA, 2020b). The measures cover various steps in the value chain such as production, transport, loading, and packaging of plastic pellets. At European and global level, Operation Clean Sweep (OCS) works towards preventing loss of plastic granules (pellets, flakes and powders). The OCS is an international programme taking all stakeholders and parts of the value chain in to consideration (OCS, n.d.).

A proposal from the European Commission has been presented by the REACH Committee in 2022. The proposal relates to the amendment of *Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards synthetic polymer microparticles*. This includes a proposal on reporting requirements for the release of microplastics from industrial plants producing plastic pellets. The requirement would enter into force after 24 months implemented (European Commission, 2022b). Changes and updates are to be expected before a final proposal is to be voted upon.

In addition pellets are included in the EU initiative " Microplastics pollution – measures to reduce its impact on the environment" (European Commission, 2022a) and in the EU-project "Study on unintentional release of microplastics" (Bio Innovation Services, 2022).

Industrial production of plastic pellets

There are currently two producers of primary plastic pellets in Sweden. Inovyn AB produces suspension-PVC (grain size of about 0.1 mm) and paste-PVC (grain size of about 0.02-2 microns) while Borealis AB produces PE pellets. Both companies are located in Stenungsund (Swedish EPA, 2017). Inovyn AB has a permit to produce up to 260,000 tons of PVC pellets per year. Borealis AB has a permit to produce up to 750,000 tons of PE pellets per year.

Industrial producers of plastic products and handlers of plastic pellets

There is no available list summarising the industrial producers of plastic products or handlers of plastic pellets. In accordance with the methodology utilised by Swedish Environmental Protection Agency (2020) to estimate the number of facilities handling plastic pellets, a search in the Swedish Environmental Reporting Portal (SMP)[25] was conducted in September 2022. This showed that there are 78 establishments that have business code 25.20[26] as their main activity, and three facilities which have handling of plastic pellets as a side business. In the case of business code 25.40, three facilities have it as its main activity and none as secondary activities. There

[25] SMP (2023, September) https://smp.lansstyrelsen.se/
[26] Detailed business code descriptions in the Swedish Environmental Assessment Ordinance (2013:251), chapter 13-Rubber and plastic goods.

are also facilities with notification requirements (business codes 25.30 and 25.50) that are not registered in the SMP, rather there are registered by the respective municipality.

It was not possible to propose a suitable indicator for handling of plastic pellets or plastic products. This is mainly due to a lack of relevant data, the high uncertainties that an indicator would entail, the complexity of the management system and the large number of stakeholders involved.

Proposed indicator

Introduced reporting requirement of microplastics emissions for all Swedish producers of plastic pellets

The requirements connected to emissions of microplastics currently differ for the two producers of plastic pellets in Sweden. Inovyn AB may discharge a maximum of 6 tons of PVC a year to water flows that are connected to the wastewater treatment plant (WWTP). This constitutes mainly flows of process wastewater but also some stormwater from wells adjacent to production that are considered polluted[27]. Stormwater from the facility is led to a surface water basin and later released to Askeröfjorden. Inovyn AB has notified and reported to County Administrative Board of Västra Götaland that approximately 20 to 40 kg of PVC is released to Askeröfjorden from the surface water basin each year. Due to this, the company is required to investigate and develop proposals for possible treatment of stormwater and the results will be presented in the first quarter of 2023[28].

The permit for Borealis facility in Stenungsund does not impose any requirements on how much microplastics they can discharge to water (Swedish EPA, 2020b). However, since 2020 they carry out daily measurements and analyses of suspended matter in their process waters and stormwater. In 2022, they submit the results of their measurements to the licensing authority to determine how the function of the filters should be checked. A study conducted in 2018 estimates that about 3 to 23 million pellets are lost at Borealis AB annually (Karlsson et al., 2018). Changes in the wastewater treatment at the facility may have changed since then.

The licencing authority can, if deemed appropriate, update and include in the permit what the facility should do to minimize emissions of

[27] The Unit for Industry, Sewage and Infrastructure Supervision at the County Administrative Board of Västra Götaland. Email 4th of October 2022.
[28] The Unit for Industry, Sewage and Infrastructure Supervision at the County Administrative Board of Västra Götaland. Email 4th of October 2022.

microplastics such as emission permits. The results of such requirements must then be presented in the annual environmental report submitted by the company[29]. Since there is a proposal at EU level to introduce reporting requirements for production facilities of plastic pellets, this could contribute to Borealis AB being obliged to analyse their water for the release of microplastics.

Data availability

The measured amount of emitted microplastics to water by Inovyn AB facility in Stenungsund is presented in their annual environmental report, which is submitted annually. If similar reporting requirements can be imposed on Borealis AB, their emissions could also be retrieved from their annual environmental report. However, relevant data is not currently available. In dialogue with the County Administrative Board of Västra Götaland, the regulator of the Borealis facility, the perception became that it can be difficult to update the company's permit to take microplastics into account. If the proposal with requirements for reporting microplastics is introduced at EU level, Borealis AB will have to report its emissions (European Commission, 2022b).

Sampling and analysis

According to Borealis AB control program they do daily sampling in effluent water for analysis of nutrients and TSS. These samples could also be analysed for microplastics according to relevant ISO standard, see Appendix I.

System boundaries

The indicator is limited to the production of plastic pellets and only releases of microplastics to water are considered.

Recipient

The recipient of treated process water and stormwater, form both Inovyn Ab and Borealis AB, is Askeröfjorden.

Representativeness

As Sweden only have two producers of plastic pellets the indicator represents the releases of microplastics to water. However, emissions to air and the adjacent nature are not covered by this indicator.

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[29] Sven Bomark. Technical advisor at the Swedish Environmental Protection Agency. Email 16th of September 2022.

Uncertainties of the methodology

There are several uncertainties associated with this indicator.

- Analyses of microplastics are yet not standardized, which affects how reliable the results are, see Appendix I. PVC is a heavy density plastic, approx. 1.4 g/cm^3, so these particles are found almost exclusively on the bottom, while PE-particles are light, around 1 g/cm^3, so they will wash up on the beaches quickly and lie in the seaweed belt. Analysis of receiving water is therefore not meaningful.
- It is unclear if the proposal on the reporting requirement for microplastics will be introduced or not. If the proposal is not accepted, it has not been possible to determine whether it is possible to add such requirements to the supervision of the facilities in Sweden.

Estimated costs

Depending on the European Commission's proposal on introducing reporting requirements is enforced or not, the approach will differ. However, if the requirement of measuring releases of microplastics is to be implemented in Borealis AB's license, the cost of this indicator is expected to be *medium* as new analyses of microplastics need to be carried out, but existing effluent control programs can be used so no additional sampling is needed.

Laundry of synthetic textiles

Microplastics that originates from laundry of synthetic textiles, both from households and businesses, end up almost exclusively in the wastewater. A part of the microplastics that end up in the water at Sweden's water wastewater treatment plants (WWTP) thus originate from washing textiles. In this study, the proposed indicator for wastewater includes analysis of the amount of microplastics from synthetic textiles. An indicator for estimating the losses of microplastics from washing of synthetic textiles would favourably be combined with one of the indicators proposed for wastewater. Information about this presented in the section about *wastewater.*

Antifouling and architectural paint

Paint products are used in a wide variety of applications and sectors but investigating potential indicators for all sectors was not considered possible within this project. This study was limited to two prioritised areas, architectural paint and antifouling paint including protective coatings for boat hulls. Paints are pigmented coatings applied to objects for decorative and/or protective purposes. They mainly consist of pigment, binders, additives, and solvents. Binders are often based on carbon-chain polymers which are added to create the solid film layer after application. The polymers form a matrix which retains the additives and pigments embedded in the paint (Faber et al., 2021). The binders most used are synthetic polymers such as alkyd, acrylic, polyurethane, epoxy and chlorinated rubbers (Paruta et al., 2022). However, some types of paint (e.g., antifouling paint) only rely on rosin, while others consist of a mixture of polymers and rosin[30].

As aforementioned, paints are used in a wide variety of sectors and different types of paint are designed for different purposes. Polymers may exist in paint as either dispersed (water-based paint) or dissolved (solvent-based paint) (Faber et al., 2021). The polymer content, composition and identities may vary broadly among different types of paint[31].

Dried paint particles < 5 mm in size should be classified as microplastics according to Swedish EPA's definition, which is similar to the definition used by the European Chemical Agency (ECHA, 2022). However, when estimating the microplastic release from paint, issues arise when considering which ingredients that should be considered microplastics. Even if additives and fillers are ingredients that can be expected to be trapped inside the polymeric network[32] and these ingredients could be important from physical, environmental, and toxicological perspectives they are often omitted in flux calculations (Turner, 2021). Microplastic particles can be emitted from wet paint during application, or from dry paint upon removal or due to weathering and poor waste management. Emissions also arises from unused paint or in association with EOL painted objects.

There is a general lack of knowledge about the total contributions of emission of microplastics from paint. Estimations are often based on theoretical calculations focusing on either one or a few sectors. The results vary depending on the causes that has been accounted for, and which wear and tear as well as removal rates has been used (Paruta et al., 2022). The same study proposed new more detailed modelling approaches for different causes of emissions e.g., the wear & tear and removal processes, and for the

[30] The Swedish Product Register at KemI (the Swedish Chemical Agency). Email October to November 2022.
[31] The Swedish Product Register at KemI (the Swedish Chemical Agency). Email October to November 2022.
[32] IVL Swedish Environmental Research Institute. Interview November 2022.

soil to waterways transport. The calculations were based on several assumptions e.g., loss rates and number of repaint jobs. The values were based on published literature and statistical data. The total global releases of microplastics from six different paint sectors was estimated and similar values for each sector were determined to identify the most important sectors. The study also pointed out the most important causes of released microplastics within each sector, as well as geographical variations. The split of emissions caused from application, weathering, removal and EOL varied between different sectors and regions.

For both architectural and antifouling paint (AF paint) little information has been found on emission factors (loss rates). No acknowledged methods of determining those factors have been found and using values determined for other regions would not necessarily provide a more detailed understanding. For the two paint sectors, one possible indicator could be described.

Architectural paint

Architectural paint is used on the exterior and interior of buildings. Specific applications include roof coatings, wall paints and deck finishes. Except from providing aesthetic characteristics, exterior coatings are highly designed for functional purposes. The category includes paint for walls on buildings, fences, roofs, tanks or similar. This section presents the investigation of possible indicators for exterior paint while interior paint has not been further considered. Even if the interior paint demand can be expected to be higher than the exterior paint demand, exterior paint was prioritised in this project due to its higher chances of leakage, where both removal work and wear and tear often lead to direct losses to the environment (Faber et al., 2021; Paruta et al., 2022).

The architectural paint sector is recognized as one of the larger contributors of release of microplastics from paint on a global scale, accounting for 48% of the global paint-related plastic pollution (Paruta et al., 2022; Swedish EPA, 2017). Paruta et al (2022) showed that most of the paint stay on the building until the EOL. Only around 15% will be lost to the environment during wear and tear and 10% will be lost through repaint. Leakage rates were determined to 23% for interior paint, 71% for exterior wood and 46% for exterior concrete. However, while the study investigates the global situation, the contribution of microplastics from exterior paint during weathering may be another in Sweden (Paruta et al., 2022). For example, there is a common trend of wood houses for private usage. The release of microplastics during weathering is thought to be a result from degradation by UV irradiation. Painted surface texture, quality of paint, building orientation, distance from sea (atmospheric levels of salt), wind and rain are main parameters affecting degradation (Gaylarde et al., 2020).

There is however a general lack of knowledge about the emissions from architectural paint. Overall, only a few studies could be found based on actual measurements of releases of microplastic particles. Estimations in literature have often been based on theoretical calculations and have not necessarily been following the same modelling approach. In a Swedish study from 2016, national emissions from protective and decorative coatings on buildings was estimated to 93 tons per year (Magnusson et al., 2016). Estimations were based on sales volumes of protective coatings on the European market 2001. Values for Sweden were determined by assuming the same proportion of sold paint per capita as in Europe. The emission factor was assumed to be 6.4% (also accounting for emissions to water and soil) and the content of binders in most protective coatings was 40%. Emissions from decorative coatings were estimated in the same way but with two available emission factors of 1.5% and 5%. From this, decorative coatings were estimated to account for 35-158 tons of the annual release in Sweden (Magnusson et al., 2016).

Even if more detailed modelling approaches has been proposed by Paruta et al. (2021), these could not be proposed as a suitable indicator for architectural paint at this stage. As mentioned, several assumptions have been made and the used values (based on literature) may not be representative for Sweden. Using the models for an indicator would require a lot of continuously updated data, specific for the Swedish conditions. In addition, there is today no available data on the emission of either plastics or microplastics from recycling facilities, and no available data on the quantities of paint remaining on EOL objects.

Antifouling paints and hull coatings

In this section discussions about possible indicators for AF paint and protective coatings (for boat hull) for commercial vessels and leisure boats are presented. AF paint is used to protect the boat hull from biofouling (growth of aquatic organisms). The antifouling properties can be provided through physical or biocidal mechanisms. There are several types of paint available for hull maintenance of leisure boats and commercial vessels (Ejhed et al., 2018). Hull coatings for commercial vessels include both corrosion protective paint and AF paint (Swedish EPA, 2017) and their chemical composition generally differs between different paints. Alike other paints, AF paint and protective coatings consists of binders. The binders can either consist of polymers, a combination of polymer and rosin, or simply rosin. While binders in AF paint often consists of rosin, binders in protective coatings generally are made up of synthetic polymers[33] (Aurell et al., 2017; Gaylarde et al., 2020). In 2021 around 93% of the AF paint products (containing biocide) put on the Swedish market contained rosin, 87% contained both rosin and polymers and 5% were based only on rosin[34].

Emissions of microplastic may arise when paint flakes or paint particles are released from boats during use (weathering) or maintenance (cleaning, scraped and re-paint). Maintenance of leisure boats in Sweden is often carried out in close vicinity to the sea and the main part of the leakage can be expected to end up in the environment (Ejhed et al., 2018). Ship maintenance is mainly carried out abroad and is mostly associated with poor waste management (Magnusson et al., 2016; Paruta et al., 2022). Removal of hull paint (AF and protective coatings) of commercial ships takes place during dry docking and potential releases highly depend on the waste management systems available. The waste management appear to vary even between specific boatyards in Sweden. (Ejhed et al., 2018). Except maintenance and weathering, the use of the vessels contributes to considerable amount of microplastic releases as well as at ship graveyards at EOL (Gaylarde et al., 2020; Paruta et al., 2022).

Release of microplastics from marine coatings and antifouling paint has attracted increased attention after the publication of a study conducted by Dibke et al. (2021). Their findings indicate that the contributions of emissions from marine coatings (including AF paint) are much higher than previously estimated and large emissions take place during use (Dibke et al., 2021). Even if the Swedish EPA has estimated that the emissions of microplastics from AF paints and other coatings for boat hulls make up a relatively small part of the total emissions in Sweden, the wear of paint flakes and particles often take place in sensitive areas and is expected to accumulate at sites of boat maintenance. Marine paint and coatings have therefore been identified as an important source of microplastics (Lusher and Pettersen, 2021; Swedish EPA, 2022).

There is generally little information available about the actual presence and distribution of plastic particles originating from these paints (Ejhed et al., 2018), and most studies of AF paint have focused on the biocides. Today no standardised or harmonised methods for collecting, preparing, and analysing environmental samples for microplastics exists, see Appendix I. Several estimations of microplastics originating from AF paint and/or protective

[33] The Swedish Product Register at KemI (the Swedish Chemical Agency). Email October to November 2022.
[34] The Swedish Product Register at KemI (the Swedish Chemical Agency). Email October to November 2022.

coatings have been carried out, of which many are based on theoretical calculations. Some of them address emissions that arise during use (Dibke et al., 2021; Magnusson et al., 2016) while others focus on emissions associated with maintenance work (Ejhed et al., 2018).

IVL Swedish Environmental Research Institute (Magnusson et al., 2016) estimated the emissions of microplastics from commercial vessels and leisure boats based on annual consumption of biocides, and on information on biocide and polymer content. This was complemented by EFs (during the lifetime of the paint) for commercial and leisure boats, respectively. In the recent study by Paruta et al. (2021), it was suggested that marine paint accounts for 12% of the global paint-related plastic pollution. Estimations were here based on more detailed modelling calculations covering a wider range of loss types compared to earlier studies.

Another possible way to follow-up the emissions could be to look at the performance of boat maintenance in combination with related waste management. Instead of estimating the total emissions this would be a way of evaluating the environmental work performed in marinas, harbours, drydocks and shipyards. For leisure boats most boat owners perform boat maintenance on their own while only about one fifth of all owners' hands it over to marinas or boatyards (Ejhed et al., 2018; Lagerqvist, 2021). Even if some boat owners that perform the maintenance on their own clean their boats on flush plates, the efficiency of the wastewater management systems may vary (Ejhed et al., 2018). Following up changes in boat maintenance practice could somewhat indicate if the total amount of microplastics ending up in the environment could be expected to have decreased. The current state could be based on, for example:

- How much of the boat maintenance that is carried out at shipyards and marinas equipped with flush plates.
- How many boats that are painted and how often.
- The efficiency of wastewater management systems at marinas, harbours, and shipyards. However, no standardized acknowledged methods for measuring the efficiency of these systems are available today.

A new eco-labelling has earlier been developed in the Eko Marina project[35], performed by the Swedish Institute for the Marine Environment and IVL Swedish Environmental Research Institute. The project now focuses on the development of a digital tool for systematic self-inspection of the

[35] Eko Marina (2023, December) https://havsmiljoinstitutet.se/projekt/eko-marina

environmental work performed by marinas. The eco-labelling and digital tool could potentially contribute as an indicator in the future.

Proposed indicator

Weight of polymers in architectural, anti-fouling paint and hull paint put on the Swedish market

A combined indicator for architectural exterior paint and hull paint, is suggested. The indicator includes the volumes of microplastics from exterior paint as well as AF paint and other hull paint put on the Swedish market each year. The total volumes of polymers are assumed to reflect the amount of microplastics.

Data availability

Annual figures of the volume of paint put on the Swedish market can be compiled from the information provided by manufacturers and importers of paint through their annual product registration to the Swedish Product register at the Swedish Chemicals Agency (KemI)[36]. According to the legal requirements all businesses manufacturing or importing notifiable chemicals (chemicals products whose customs tariff numbers are on the list of customs numbers in Annex 1 to the Chemical Products and Biotechnical Organisms Ordinance) above 100 kg/year must report specific information to KemI. The information includes chemical composition, application area, function, and annual amounts. The categorisation into industry codes and functions are made by the company itself. To obtain information about the relevant paint products some filtering must be made. Function and industry codes under which exterior paint and AF paint has been reported, see Table 4:

Table 4: The categorisation of different paints according to function and industry code. The ones related to architectural exterior paint as well as AF paint are presented.

Architectural exterior paint		**AF- and Hull paint**	
Function	*Industry code*	*Function*	*Industry code*
Paint for exterior use	• Retail sale of paints in specialised stores • Wholesale of chemical products • Construction of buildings • Manufacture of paints, varnishes	• Antifouling paint • Hull paint	-

[36] The Swedish Product Registry (2023, December) https://www.kemi.se/en/products-register

	and similar coatings, printing ink and mastics • Specialised construction activities • Retail trade, except of motor vehicles and motorcycles		

The following paint information can be provided by KemI for each function and industry code:

- Share of ingredients reported (%), of total products
- Total quantity of products (ton)
- Total quantity of polymers (ton) or total quantity of polymers + rosin
- The share of specific polymer types of the total quantity of polymers + rosin in considered products
    - Rosin
    - Polyacrylates
    - Alkyd
    - Epoxy
    - Polyvinyl
    - Silicone
    - Polyolefins
    - Other polymers

Moreover, is it possible to obtain some information about the quantities available for consumer use, this data however is accompanied with large uncertainties.

System boundaries

The indicator is delimited to architectural exterior as well as AF paint and other hull coatings for commercial vessels and leisure boats in Sweden that has been put on the market each year.

Recipient

Since the indicator exterior paint is based on calculation models rather than actual measured occurrence of microplastics in specific environmental compartments, the recipient is “the natural environment”. The same was found for AF paint as particles are generated when boats are at sea, during re-paint and reparation work and from abandoned boats on land. The particles end up on land, in sediments, and in the ocean.

Representativeness

The data provided by the Swedish Product register at KemI can be expected to rather well represent the amount of exterior and AF paint put on the Swedish market every year. However, due to the lack of knowledge about the loss rates and release conditions in Sweden the indicator should be regarded as a simplified method that only will provide indicative information about the potential quantities and characteristics of microplastics that could possibly end up in the environment. Changes in paint formulations with respect to polymer composition and content will be indicated using this data. However, measures such as improved waste management will not be captured.

When it comes to AF paint, this indicator does not account for the emissions of microplastics arising from international commercial shipping and international leisure boats. Most of the emissions resulting from this activity could be expected to be caused by weathering under usage. This is mainly because maintenance of commercial ships is mostly carried out abroad.

Uncertainties of the methodology

According to the Swedish Product Register at KemI, it is in general difficult to identify polymers, due to lack of information about their density. During manufacturing a molecular weight interval is generally determined, and even if the exact density would be known a generalized CAS number valid for all different densities is often used. This makes it almost impossible to assess if the polymer is present in a solid form enabled to provide microplastics.

As indicator of released microplastic from paint the fundamental definition of what should be considered to contribute or produce microplastics involves great uncertainties. With this indicator we agree to consider the polymer content as reflecting the quantities of microplastics that could be derived from the paint. However, future definitions may be different and the comparability of those results with future information may be compromised.

Even if the data available from the Swedish Product register at KemI is expected to contain information covering the main part of paint products put on the Swedish market, and even if a large part of polymers are reported, some uncertainties remain.

- Not all paint products must be reported and hence there will be a number of unreported cases.
- Some uncertainty arises from the fact that the companies themselves categorise their product within the different industry-

and function codes. This means that products of the same type could end up in different categories. However, using the above selections the exterior paint, AF paint and hull paint can be expected to be well represented.

- Only ingredients classified as hazardous to health or to the environment, that are contained in a concentration at or above 5% must be reported. This means unreported amounts of ingredients of unknown identity and concentration. Information about the total percentage of reported content can though be provided, giving indications of the size order of unreported ingredients (Appendix I). In 2021 around 88% of the total mass of hull paint products were reported.
- Paints can be reported as families meaning that one paint family can be covered by one report. In those reports concentrations of ingredients are accepted to be reported as intervals.
- The identity of polymers is often unknown by the notifier, implying uncertainties with the presented share (%) of different polymer types.
- If paints are reformulated to only contain unclassified polymers in a concentration <5% compiled data will show a decrease in the quantities of polymers reported. This may falsely indicate a decreased mass of polymers put on the market. It is therefore important to also follow the figures presenting the percentage of total reported compositions.

Like the situation for tyres and architectural paint, calculations based on emission factors are highly affected by the EF values used. Encountered EF values for paint losses during the life cycle of boats are not Sweden-specific and often not based on actual measurements (Ejhed et al., 2018; Lassen et al., 2015). Several studies refer to OECD, 2009 and some estimate their own values based on OECD 2009 in combination with other information. The loss rates however, may differ broadly between countries (even between Scandinavian countries), not least depending on the waste management (Magnusson et al., 2016). Furthermore, is it possible that the loss rates have changed since 2009.

Estimated costs

As the data is already provided by the Swedish Product Register at KemI, the costs of the indicator exclusively depend on the time required for the compilation of reported data. The cost of the indicator is therefore assumed *low*.

Littering

At global level, plastic litter constitutes 83–87% of all marine litter. Land-based sources are estimated to be responsible for approximately 80% of marine litter. The largest portion of plastic associated with marine pollution is often linked to the contribution from terrestrial sources related to accidental or deliberate spills as well as inefficient waste management systems in heavily anthropized coastal regions (Gomiero et al., 2018).

Secondary microplastics are where larger plastic items undergo degradation and subsequent fragmentation that leads to the formation of smaller plastic pieces as they start to break down by mechanic-, photo-oxidative degradation followed by thermal and/or chemical degradation (Wright et al., 2013).

According to the government's regulatory letter in 2020 and the ordinance (2021:1002) (Riksdagsförvaltningen, 2020) on littering fees, the Swedish EPA must expand the state of knowledge regarding littering in Sweden by developing a system for national litter monitoring as a basis for implementing the EU's single-use plastics directive (European Commission, 2019).

Test measurements were carried out by the Keep Sweden Tidy Foundation[37] in 75 municipalities' central locations over the course of a week. During that period, it was estimated that 3.3 million plastic items were thrown away in all of Sweden's 290 municipal central areas in total. The weight of the plastic items was estimated at 8 tonnes (Swedish EPA, 2020a).

The first reporting year for the national litter monitoring in Sweden is 2023.

Proposed indicator

Measurements of macro litter as an indicator for microplastics

Possible indicators for following up microplastics from littering is to study the amount of macro plastics that end up in nature. Two alternative approaches are proposed in order to be able to follow up littering in Sweden:

1. Total amount (kg) of plastic litter estimated in the future annual national plastic litter monitoring program.
2. Total amount (kg) of plastic litter collected annually in selected representative urban monitoring sites by The Keep Sweden Tidy Foundation (HSR).

[37] Keep Sweden Tidy Foundation (2023, December) https://hsr.se/keep-sweden-tidy-foundation

Data availability

The consortium SMED[38] is at present commissioned by the Swedish EPA to develop methodology for national litter monitoring. It should be applied 2023 to assemble sufficient data to fulfil requirements for reporting to the EU's single-use plastics directive. There are however no data available at present through this program.

HSR[39] carries out structured litter measurements regularly (usually every year) in around 80 municipalities. The litter monitoring consists of urban area with measurements taken in both park and city centres. In addition, monitoring is also conducted in nature where measurements are made on trails and rest areas as well as beaches. The natural measurements are carried out before cleaning, while urban sites are monitored stochastically. HSR communicates the information via its statistics portal, and it is available and free for everyone.

The plastic categories analysed by HSR consists of:

- Cellophane from cigarette packs
- Beverage bottle/drink packaging
- Disposable gloves
- Disposable mug
- Candy / snack / ice cream packaging
- Loose corks and lids
- Food packaging
- Snuff box
- Plastic bag
- Plastic, other

System boundaries

The suggested indicators are both based on the assumption that there is a correlation in-between macro- and microplastics present in the urban environment.

Recipient

Urban areas and nature areas.

Representatives

Both monitoring programs used as basis for suggested indicators should be representative for targeted urban areas with municipal waste management

[38] Svenska Miljöemissions Data (SMED) (2023, December) https://smed.se/
[39] Britta Lönn, HSR (2022, September 6)

responsibility in respective city and littering can be evaluated over time, but it is not possible with reasonable uncertainty to scale this up to national levels outside urban areas. The magnitude of littering varies a lot for example along the Swedish coast due to predominate directions of wind and ocean currents and the presence of possible point sources.

Sampling and analysis

The sampling methods for litter is well defined and described in both suggested monitoring programmes. However, there are no emission factors available describing relationship between macro plastics and microplastics, while macro plastics is suggested as a proxy for microplastic.

Uncertainties of the methodology

Even if about 80 municipalities are participating in the HSV-program it is still less than 30% of the municipalities in Sweden. The participating municipalities might also be more active in preventive measures leading to extended uncertainties in up-scaling of results, while there is an advantage to use data from the national monitoring programme when available.

Estimated costs

Low cost while data is available from existing or planned monitoring program.

Pathways for microplastics

In this chapter, indicators related to the included pathways are presented. The pathways are presented in the following order:

- Wastewater
- Stormwater
- Wind

Wastewater

Municipal wastewater treatment plants (WWTPs) receive wastewater from domestic entities like households, shops, offices etc. and to a varying degree stormwater from urban areas and wastewater from industries. Some urban areas in Sweden have combined sewer systems, mainly old city centres, whereas others have separate systems for wastewater and stormwater. The origin of the wastewater will have a large effect on the abundance and character of the microplastic particles.

There are several studies postulating WWTPs as one of the major pathways of microplastics to the environment (Kay et al., 2018; Mintenig et al., 2017; Prata, 2018). There are also a great number of studies that report an efficient removal of microplastics in WWTPs (Baresel and Olshammar, 2019; Carr et al., 2016; Gies et al., 2018; Prata, 2018; Tumlin and Bertholds, 2020).

Table 5. Average removal efficiency for microplastics ≥20 µm (%) (Baresel and Olshammar, 2019)

Treatment technique	Average removal efficiency for microplastics (%)
Primary treatment	85
Secondary treatment	90
Tertiary treatment	95
Sand filter	97
Microfiltration	98

The vast volume of wastewater treated in Sweden each year, however, implies significant amounts of microplastics entering the environment even if the concentrations of microplastics in the WWTP effluents may appear modest.

Sanitary sewer overflows (SSO) are conditions where untreated wastewater is discharged from a sanitary sewer into the environment, normally due to lack of process or hydraulic capacity. There are three main types of SSO, i.e., technical SSO, weather event SSO and SSO at WWTPs. Technical SSO describe sewer overflows caused by technical failures of pump stations or other sewer installations. Technical SSO occur at no specific flow conditions in contrast to the other two types of SSO and the wastewater holds normal concentrations of microplastics. Weather event SSOs appear in the sewer network when the hydraulic capacity of the sewer is exceeded due to high inflow of stormwater. This may bring a substantial amount of microplastics from connected surfaces, even if the concentration is low due to the large discharge. SSO at WWTPs due to hydraulic capacity limitation of the WWTP normally mean that the discharged water undergoes at least partial treatment. As this partial treatment often targets particulate phosphorous, a good removal effect is also achieved on microplastics. A study by IVL Swedish Environmental Institute (Baresel and Olshammar, 2019) clearly indicate that SSOs even in Sweden are a significant source of microplastics to recipients. This despite the relatively small share of total water flows of SSO due to the good overall retention of microplastics in the main water stream of Swedish WWTPs.

About 10% of the Swedish population is not connected to municipal wastewater treatment systems, but to small scale on-site treatment facilities normally consisting of a septic tank (mechanical treatment) with or without further treatment (Olshammar et al., 2015). For 26% of the properties that only have septic tanks, the reduction of microplastics is moderate. Meanwhile, soil infiltration systems are considered to be efficient in reducing microplastics based on the studies on large WWTPs presented previously and on their efficiency in reducing load of suspended solids in general.

Microplastics treated in WWPTs are mainly retained in sewage sludge. The reported amount of sewage sludge produced in Sweden in year 2020 amounted to 208,348 tonnes of dry matter. The proportion produced sewage sludge that was spread on arable land continued to increase and in 2020 amounted to 96,328 tons dry matter and made up 46 percent of all use (SCB, 2020). In order to spread sludge on arable land in Sweden the sludge needs to be certified according to the Revaq-system[40]. According to this system, the sludge needs to be analysed for pollutants before being spread and fulfil certain quality criteria. Currently, there are no quality criteria for microplastics in Revaq.

[40] https://www.svensktvatten.se/vattentjanster/avlopp-och-miljo/kretslopp-och-uppstromsarbete/revaq-certifiering/

The present EU-directive concerning urban wastewater treatment from 1991 does not consider microplastics, but the newly published proposal for updated directive is (European Commission, 2022c). The stated reason for this is that “the scientific community, policy makers and the general public see the growing evidence of contaminants of emerging concern, including micro-pollutants such as pharmaceuticals and micro-plastics in water bodies, as an increasingly important issue”.

It is therefore suggested that by 2040 microplastics emissions would be reduced by 9% from wastewater. This means that member states will have to monitor pollution from stormwater and sanitary sewer overflow (SSO) in the outlets of WWPTs, and the presence of microplastics (including in sludge).

For all agglomerations of above 10 000 population equivalents (p.e.), member states shall monitor, at the inlets and outlets of WWPTs, the concentration and loads of microplastics. For all agglomerations of above 10 000 p.e., member states shall also monitor the presence of microplastics in the sludge (European Commission, 2022c).

Proposed indicators

Based on available data and feedback from relevant stakeholders such as Svenskt Vatten[41] the project is suggesting the following indicators for wastewater.

1. Measured mass concentration of microplastics in WWTP incoming and effluent water.
2. Total volume Sanitary Sewer Overflow (SSO) at WWTP and from the sewer system.
3. Measured mass concentration of microplastics in WWTP sludge.

Data availability

Within the Swedish EPA's Environmental Toxics Coordination's sub-programme on environmental toxins in the urban environment, occurrences of chemicals in sludge and effluent water from sewage treatment plants are monitored.

Measurements of metals and organic substances in sludge and outgoing water from nine treatment plants have been carried out annually since 2004 (Haglund, 2019). The results can, for example, be used to follow up on whether regulations or bans of a certain chemical have had any effect on the amount of that chemical found in the WWTP. Levels of unwanted

[41] Westling Klara & Östfeldt Hanna, Svenskt Vatten. Online meeting (2022, October 7)

substances in sludge and effluent water can thus serve as indicators of the impact of the urban environment on the surrounding environment. It is here suggested that existing parameters in this program is extended to include microplastics in both incoming and effluent water and sludge.

To get as representative samples as possible, the sampling takes place every year in October, during normal operating conditions and after a period of normal weather conditions. The samples are transferred to specially washed glass jars and delivered immediately to Umeå University where they are split in portions for the various analyses and for sample banking (sludge). To include microplastics, the volume of water and sludge might need to be increased. It is suggested that the samples are analysed both for quantity, i.e., total (mass) microplastics, but also for quality, i.e., particles separated into categories depending on the sources, such as textile fibers from laundry, paint flakes and TWP from road wear and abrasion of tiers (at least for WWTP with combined sewer systems).

Volume SSO is normally reported for WWTP in the Swedish environmental reporting portal (SMP) and to some extent also for the sewer system and can be used as a basis for an indicator. While SSO load of microplastics can be in the same magnitude as the main stream it is suggested to have a separate indicator for this load (Baresel and Olshammar, 2019).

System boundaries

The average measured microplastics concentration can based on water flow be scaled up to the whole of Sweden, but the suggested indicator is for selected plants with treatment technology representing the whole population of WWTP in Sweden.

Total volume SSO should be submitted yearly in the reporting system SMP[42] for each WWTP and sewer network.

Recipient

Recipient water and sludge.

Representativeness

Suggested indicator can be used to represent conditions in the whole of Sweden.

[42] https://smp.lansstyrelsen.se/

Sampling and analysis

It is suggested that mass of total microplastics, tyre wear particles (TWP) and other “black anthropogenic particles” and textile fibers are analysed in both incoming and effluent wastewaters and in sludge with relevant methods presented in Appendix I.

Uncertainties of the methodology

Microplastic concentration and weight in wastewater is hard to compare between studies if/when different sample methods and analyses methods of different particle sizes have been used. This is especially true for sludge and incoming wastewater where other organic material needs to be digested before analysis without harming microplastic particles.

Another uncertainty issue is that often very small volumes are analysed for microplastics in order to represent concentrations in large flows of water and sludge, where the concentration is likely to be heterogenic.

Estimated costs

The project assesses the cost for implementation of suggested three indicators to be *medium* as long existing monitoring programs are used. Meaning that the extra cost will be for analysis of microplastics in existing samples and data assessment. If the suggested new wastewater treatment directive is implemented (European Commission, 2022c) all necessary data will be available freely through the yearly environmental reporting by the WWTP´s.

Stormwater

Stormwater develops as precipitation such as rain or melting snow runoff from paved urban surfaces. As paved surfaces prevent water from infiltrating into the ground it is to large extent the number of paved surfaces and activities on it that regulate the volume and quality of stormwater that is developed within a specific area.

All outdoor activities that generate plastic debris are potential sources to microplastics present in stormwater, e.g., construction and maintenance work, traffic (particles from road surface and tyres) and littering. A substantial amount probably derives from large plastic debris that has been degraded to microplastics. Stormwater is either drained into the sewage system and treated in WWTP´s (combined sewer system) or transported separately to the recipient with or without stormwater treatment. In Sweden combined systems make up only about 12% of the existing sewer systems (Olshammar and Baresel, 2012) meaning that most of the stormwater is not treated in WWTPs. Extreme rains not only increase the volumes of stormwater, but it also increases the forces by which microplastic particles are washed off paved surfaces, both factors leading to more microplastics being transported with stormwater to water recipients even if the concentration can be low due to high dilution.

Microplastics have been quantified and characterized in urban stormwater runoff from 12 watersheds surrounding San Francisco Bay. All stormwater runoff contained anthropogenic microparticles, including microplastics, with concentrations ranging from 1.1 to 24.6 particles/L. These concentrations are much higher than those in wastewater treatment plant effluent, suggesting urban stormwater runoff is a major source of microplastics, to aquatic habitats. Fibers and black rubbery fragments (potentially tyre and road wear particles) were the most frequently occurring morphologies, comprising ~85% of all particles across all samples (Werbowski et al., 2021).

Data on microplastics in stormwater from different land use classes are scarce but a study conducted in Denmark analysed microplastics in stormwater from three residential areas, two industrial areas, one commercial area and from a highway in North Jutland (Liu & et al, 2019). In the residential areas the microplastic content varied between 0.128–0.231 μg/l, in the industrial areas between 0.521–0.664 μg/l, the commercial area 1.143 μg/l and from the highway 0.085 μg/l was measured.

The establishment of standardized monitoring methods for assessing microplastics in stormwater and standardized analytical methods for evaluation of microplastics in stormwater has been proposed by (Shruti and et al, 2021), but is still far from implemented in any monitoring program.

Stormwater is complicated and expensive to monitor since volume based sampling during complete rain events and chemical analysis of the samples is needed to assess pollution transport (Viklander et al., 2019) . Several monitoring campaigns during different seasons are necessary to give good understanding of the stormwater pollution situation in one monitoring site and the results are questionable to extrapolate to other areas. There is however a model called StormTac frequently used in Sweden to calculate pollution load from stormwater based on standard concentrations of pollutants from different land use classes in combination with runoff coefficients. There is however at present not enough data available to use this model to assess microplastic transport via stormwater[43].

[43] Larm, Thomas. CEO at StormTac Ltd. E-mail (2022, September 14).

Proposed indicator

There is a general lack of data for microplastics in stormwater and it is hard to evaluate mitigation measures with an indicator since natural variation in flow conditions varies considerable in-between different years. The project is therefor only suggesting one cost-efficient indicative indicator for microplastics in stormwater.

1. Measured mass concentration of rubber particles in WWTP incoming water.

Data availability

Measurements of metals and organic substances in sludge and outgoing water from nine treatment plants have been carried out annually since 2004 within Swedish EPA´s Environmental Toxics Coordination's sub-program on environmental toxins in the urban environment, occurrences of chemicals in sludge and effluent water from sewage treatment plants (Haglund, 2019).

It is here suggested that existing parameters in this program are extended to include rubber particles in incoming water, which can be combined with the analysis proposed for wastewater. Only WWTP´s with combined sewer systems should by analysed for SBR. Even if most WWTP´s need to manage substantial inflow and infiltration (I&I) in sewage systems it is important to distinguish in-between fast and slow I&I instead of the percentage of I&I (Clementson et al., 2020). Infiltration water is unlikely to contain substantial amounts of microplastics, while the indicator should focus on WWTPs with fast inflow of stormwater in their sewer systems.

System boundaries

By analysing only rubber particles in incoming wastewater the indicator will only target spread of mainly tyre wear particles (TWP) and SBR-rubber infill from artificial grass pitches via stormwater. The reason for choosing only black rubber particles as indicator is that most other microplastics are present not only in stormwater but in other wastewaters fractions such as from household and industries and SBR is a main microplastics component in stormwater (Werbowski et al., 2021).

Recipient

Recipient water and sludge.

Representativeness

The indicator has low representativeness for the whole of Sweden, while it will depend local conditions such as sewer system (inflow of stormwater), land use and urban activities.

Sampling and analysis

Black particles and rubber particles are difficult to analyse with µ-FTIR, because of their high absorption of infrared radiation. By using an ATR crystal in conjunction with the IR-instrument, black particles and rubber particles can be analysed separately from other microplastics. Particles with diameter between 40 µm and 5 mm can be counted and identified (ALS, 2020). Incoming waters are challenging to analyse while other organic substances need to be digested before analysis.

A synthesis article (Shruti and et al, 2021) showed that 8 out of 11 studies evaluating microplastics in stormwater used the analytical method (ATR-FTIR).

Uncertainties of the methodology

SBR can to some extent also be present in household water from laundry of sport clothing, etc.

Estimated costs

The project assesses the cost for implementation of the suggested indicator to be low if the suggested indicator for wastewater is implemented, since only one additional parameter in incoming water should be analysed.

Wind

A review of microplastics in atmospheric fallout show few available studies but available results indicate that synthetic textiles are main source of airborne microplastics, and fibers are the dominant shape of microplastics in the atmosphere. Meteorological conditions and human activities affect the distribution and deposition of airborne microplastics (Chen et al., 2020).

The total atmospheric fallout was investigated at two sampling sites in Paris: one in a dense urban environment and one in suburban environment. Only fibers were encountered, and fragments were not detected. Throughout the year of monitoring (site 1), the atmospheric fallout ranged from 2 to 355 fibers/m^2, day indicating a high annual variability. On site 2, the atmospheric fallout was 15 to 91 fibers/m^2, day. The suburban site systematically showed fewer fibers than the urban one (Dris et al., 2018).

In an IVL study (Magnusson et al., 2020b) atmospheric deposition of microscopic litter particles in the range 30 – 5000 µm has been analysed in samples from eleven sampling locations from the Swedish Throughfall Monitoring Network (SWETHRO). Each location has two sampling points, one for collection of the deposition as the precipitation passing through the forest canopies, so-called throughfall, and one for collection of the bulk deposition with precipitation to the open field.

Bulk deposition mainly reflects the wet deposition. Data from these two sampling points can be used to calculate dry and wet deposition of airborne substances to forests and to the open field. The sampling locations are spread out over Sweden and represent three categories depending on their position in relation to urban areas. Deposition of all the micro litter fractions, including plastic fibres, plastic fragments, tyre weir particles (TWP) and non-synthetic textile fibres, were detected at most of the sampling locations.

TWP was the dominating category at the locations in cities, and the highest detected concentration was found in central Malmö, 433 TWP/m^2/day. Deposition of microplastics (plastic fibres + plastic fragments) varied between 0 and 70 particles/m2/day at the different locations. Plastic fibres dominated in numbers over plastic fragments at 14 of the 20 sampling points. No consistent difference in micro litter deposition could be detected between the samples from the throughfall and the bulk deposition to the open field, and hence the obtained data could not be used to separate dry and wet deposition of particles. The results from the study show that microplastic particles can be monitored using existing monitoring network.

Proposed indicator

Measured bulk deposition of microplastics

Total yearly average concentration of microplastics in bulk deposition water analysed based on volume proportional monthly samples.

Data availability

No data available today but could be readily generated by analysing deposition samples from the Swedish Throughfall Monitoring Network (SWETHRO) also for microplastics.

System boundaries

The deposition of microplastics can be scaled up to the whole of Sweden even if the suggested indicator is for specific monitoring sites.

Recipient

The whole of Sweden.

Representativeness

The map below, Figure 1, shows the eleven sites across Sweden that today have simultaneous measurements of throughfall, and bulk deposition chosen to well represent background deposition in Sweden. Seven of these measurement sites are financed by Swedish EPA. The samplers responsible for these sites are used to handling more advanced sampling so they should also be able to handle the sampling for microplastics.

Figure 1. Map of present deposition monitoring stations in Sweden[44].

The existing monitoring network (SWETHRO) is established to describe background deposition situation in the whole of Sweden, which also will be

[44] Swedish Throughfall Monitoring Network (2022, December 11) https://krondroppsnatet.ivl.se/

the case for microplastics. The indicator will however not describe the situation in urban areas.

Sampling and analysis

Suggested analysis method for microplastics in deposition (particles in water) is μ-FTIR (Fourier Transform Infrared Spectroscopy) where the type of plastic can be identified. With this method, particles with a diameter between 40 μm (20 μm for pure waters) and 5 mm are counted and identified, with the exception of black particles. Black particles and rubber particles are difficult to analyse with μ-FTIR, because of their high absorption of infrared radiation. By using an ATR crystal in conjunction with the IR-instrument, black particles and rubber particles can be analysed separately from other microplastics. Particles with diameter between 40 μm and 5 mm can be counted and identified. (ALS, 2020).

Uncertainties for the methodology

Estimated costs

The cost for this indicator is expected to be medium, while it includes minor extra work in the field, some sample preparation, microplastic analysis in lab, data analysis and reporting.

Summary of proposed indicators

Table 6 presents a summary of the proposed indicators for the included sources and transport routes. For each indicator, the name of the indicator, the proposed method, and the scope is presented.

Table 6. Summary of indicators that are proposed for estimating the losses of microplastics from selected sources and pathways.

Source/pathway	Indicator	Method	Scope
SOURCES			
Tyre wear	Microplastics from tyre wear emissions based on annual traffic activity data (kg/y).	Annual traffic activity data (vehicle km) of different vehicle classes are multiplied with vehicle class-specific emission factors (g/km). The cost for this indicator is expected to be *medium to high* depending on emission factor updating frequency.	The traffic activity data covers the whole road network in Sweden. Swedish emission factors (EFs) for passenger cars and trucks will soon be available. Extrapolation is needed for other vehicle types.
Artificial grass pitches	1. Replenishment of infill on Swedish football pitches (kg/m^2, y).	The method is based on a survey sent to e.g., BEKOGRs members, to estimate the amount of replenished infill (kg/m^2, y). To scale up the amount of replenished infill to national level, an estimate of the total area of artificial football pitches could be	The proposed indicator only estimates the amount of replenished infill. The estimation should not be considered as the actual loss of microplastics, since only a limited amount of the replenished infill is lost to nature. However, it still provides valuable information about

		estimated with the help of the Swedish Football Association. The cost for this indicator is expected to be *medium.*	how the AGPs are managed and thus gives an indication of the spread of microplastics from them.
	2. Certification system for artificial football pitches in Sweden (No. certified pitches).	A certification system is introduced to provide well-managed artificial football fields with a certification showing that the facility owners have made certain measures to reduce emissions of microplastics. The cost for this indicator is expected to be *high* during build-up of the system and then *medium*.	This indicator would include certain measures being required and a minimum requirement of training of the personal managing the fields. The indicator would not provide a total amount of lost microplastics; however, the method would show whether there is a reduction in microplastics released to the environment.
Industrial production of plastic pellets	Introduced reporting requirement of microplastics emissions for all Swedish producers of plastic pellets (kg/y).	The method refers to analyses being performed on outgoing water from Inovyn AB and Borealis AB located in Stenungsund. For this, requirements need to be introduced for Borealis AB to analyse their outgoing water. Data can be available through changes of their permit or via new legislation at EU level. The cost of this indicator is expected to be *medium* as new analyses need to be carried out, but possibly existing monitoring programs can be used.	The indicator is intended to cover national emissions. Only emissions of microplastics to water are considered with this indicator.

Architectural and antifouling paint	Weight of polymers in architectural paint, antifouling paint and other hull paint put on the Swedish market (kg/y).	For each category of paint products, annual weight of paint and of polymers in the paint put on the Swedish market can be compiled from the information provided by manufacturers and importers of paint through their annual product registration to the Swedish Product register at the Swedish Chemicals Agency (KemI). The total weight of polymers in the paint are assumed to reflect the amount of microplastics. The cost for this indicator should be low while it is based on already available free data.	The data reported to the Swedish Product Register generally include products imported or manufactured above 100 kg/year. Compositional data is generally available for ingredients classified as hazardous to health or to the environment, that are contained in a concentration at or above 5%. The compiled data are however expected to rather well represent the total volumes put on the Swedish market each year.
Littering	Average yearly amount (kg/person, y) of plastic litter.	Estimations based on the annual national plastic litter monitoring program to be developed 2023 and/or the existing urban litter monitoring program run by The Keep Sweden Tidy Foundation (HSR). Low cost for this indicator is expected since data is available from existing or planned monitoring program.	The indicator is intended to reflect national urban emissions of microplastics from litter.

PATHWAYS			
Wastewater	1. Measured average load of microplastics (g/pe, y) in wastewater treatment plants incoming and effluent water.	Quantification of microplastics from wastewater through extension of the existing Swedish EPA's Environmental Toxics Coordination's sub-programme on environmental toxins in the urban environment, occurrences of chemicals in effluent water from sewage treatment plants to also include microplastics. By analysing not only total microplastics but also separately rubber particles and textile fibers the results can also be used as indicator for the source "laundry" and the pathway "stormwater", when combined sewer systems drain stormwater to wastewater treatment plants. Medium cost for this indicator is expected while existing monitoring programs are used.	The indicators are intended to reflect national spread of microplastics via WWTP effluent, sanitary sewer overflow and sludge.
	2. Reported average volume (m3/pe, y) of sanitary sewer overflow at WWTP and from the sewer system .	Indicator based on reported SSO which should be available through the annual environmental reporting. Low cost for this indicator since it is based on existing freely available data.	

	3. Measured average load of microplastics (g/pe, y) in WWTP sludge.	Quantification of microplastics from wastewater through extension of the existing Swedish EPA's Environmental Toxics Coordination's sub-programme on environmental toxins in the urban environment, occurrences of chemicals in sludge from sewage treatment plants to also include microplastics. Medium cost for this indicator while existing monitoring programs are used.	
Stormwater	Measured average load of rubber particles in WWTP incoming water (g/pe, y).	Quantification of microplastics from stormwater through extension of the existing Swedish EPA's Environmental Toxics Coordination's sub-programme on environmental toxins in the urban environment, occurrences of chemicals in sludge and effluent water from sewage treatment plants to also include rubber particles in incoming wastewater. Medium cost for this indicator while existing monitoring programs are used.	The suggested indicator can be used to see changes in-between years but cannot be för extrapolation nationally, as local conditions for stormwater varies substantially.
Wind	Measured average yearly deposition of microplastics in bulk deposition (g/m^2, y).	Measured total yearly average concentration of microplastics in bulk deposition analysed based on volume proportional monthly samples in the	The deposition of microplastics can be scaled up to the whole of Sweden even if the suggested indicator is for specific monitoring sites.

		existing the Swedish Throughfall Monitoring Network. Medium cost for this indicator while existing monitoring programs are used.	

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Appendix I – Analysis of microplastics

In 2021, a suggestion of ISO standard regarding analysing microplastics in e.g., water and soil was presented. The draft proposal was titled *Principle the analysis of plastic and microplastic present in the environment*. The proposal specifies definitions such as "macroplastics", "microplastics", and "state of degradation" (Gerhard, 2021).

The analytical steps included in the document are sampling, sample preparation and detection. Details in regard to these steps are presented in the draft which is on remittance.

In addition, there are new standard proposals within ISO for analysis of microplastics in water:

1. Water quality — Analysis of microplastics — Part 1: General and sampling (ISO/AWI 16094-1).
2. Water quality — Analysis of microplastics — Part 2: Methods using vibrational spectroscopy in drinking water and groundwater (ISO/AWI 16094-2).
3. Water quality — Analysis of microplastics — Part 3: Thermoanalytical methods in waters with low content of natural suspended solids (ISO/AWI 16094-3).

The most common methods for analysis of microplastics and their characteristics are summarised in Table 7.

Table 7: Detection methods for analysing microplastics based on a report by VTI (Andersson-Sköld et al., 2020a; Gerhard, 2021).

	Microscopic methods	Micro spectroscopic methods			Gas chromatographic methods mass spectroscopy (GC/MS)	
Analysis method	Light microscopy	SEM-EDX[a]	µ-FTIR[b]	Raman	Pyrolysis-GC/MS	TED-GC/MS[c]
Detectable amount in a sample	-	-	ng-µg	ng-µg	µg	µg
Maximum number of measurable particles per sample or quantity of sample	-	-	10^3–10^5	10^3–10^5	<20 mg	<100 mg
Time for analysis incl. sample preparation	Hours – days	Hours	Days – weeks	Hours – days	Days – weeks	Hours
Detection limit	20–100 µg	10 µg	20 µg	1-10 µg	<1 µg[d]	0,5–2,5 µg
Sample preparation	Filter	Filter	Special filter	Filter	Isolated particles (vial)	Filtrate or material in crucibles
Polymer type	No	No	Yes (hard)	Yes (hard)	Yes	Yes
Appearance of particle surface	Yes	Yes	No	Yes	No	No
Degree of degradation	No	No	No	Surface oxidation	Oxidation	No
Number of particles, size, shape and morphology	Yes, by ocular assessment	Yes, number	Yes	Yes	No	No
Mass balance	No	No	No	No	Yes?	Yes

[a] Scanning electron microscopy with X-ray detector
[b] µFourier transform infrared spectroscopy
[c] Thermal extraction and desorption GC/MS)
[d] Development is underway that can reduce the detection limit