# ROAD MARKING AND MICROPLASTICS IN SCANDINAVIA

AN OVERVIEW OF THE AVAILABLE KNOWLEDGE OF MICROPLASTICS IN THE SCANDINAVIAN ROAD MARKING INDUSTRY

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## SUMMARY


- Road markings are used to enforce traffic rules and guide drivers, pedestrians, cyclists, and other road users to their destinations in a safe and timely manner. Already today and in the future, road markings act as the railroad for driving, and they are a key in the urban environment by creating space for micromobility.

- Scandinavia was always progressive in nature conservation and there are more studies and reports available on the topic compared to other countries. Road markings reportedly contribute to the recently emerged environmental challenge the microplastic pollution. However, these studies base their calculations and estimations on peer-reviewed articles, which assume that all applied road markings will end up as secondary microplastics in the environment. These studies fail to communicate the uniqueness of road markings and how they differentiate them from decorative and industrial coatings.

- Our report summarizes the available knowledge on the topic in detail. Our definition of microplastics was based on the recent legislation on primary microplastics and the upcoming legislation on secondary microplastics. Based on the knowledge of industry experts the model was built to follow the life cycle of the road marking products and hopefully provide a better understanding of the details of whether and how road markings contribute to the issue. Furthermore, in cooperation with other road-marking associations, a simple model was developed to help estimate the correct road-marking loss in the region.

- The upcoming legislation will exempt several road marking products from the regulations and several studies suggest limited detectability of road marking-derived microplastic particles. It is highly recommended that legislation increase focuses on functional lifetime by an enhanced program of re-application standards and usage of certified high-quality road markings. Moreover, based on our review and assessment it is recommended to further investigate road marking-related microplastic emissions with the involvement of industry experts.

# Table of Contents

# 1. INTRODUCTION

Synthetic polymers, or commonly plastics, are chemically resistant and durable polymeric materials that can be shaped and moulded into any form. This property makes plastics in general a versatile raw material that many industries use to produce various items. Their physical properties made polymers dominant in our lives nowadays. Over the last decade, it become evident that the use of plastics results in the release of tiny polymers particles often referred to as **microplastics**.

There is a lack of legislative consensus on what exactly microplastic particles are. The scientific community have concluded that every polymer (excluding unmodified natural polymers) below 5 mm in size is considered a microplastic. Generally, these tiny polymer particles are classified into two categories depending on their origin. **Primary microplastics** are intentional additives to certain products, such as wash-off creams, toothpaste, or detergents. Since 2019, the addition of primary microplastics to products is strictly regulated in Europe by the European Commission. On the contrary, **secondary microplastics** are created when plastic polymers, mainly plastic waste are exposed to physical and chemical factors in nature. Microplastic particles are ubiquitous in the environment, and studies proved that these particles are a threat to the environment in many ways. In the aquatic environment, it can be harmful to smaller animals. These tiny plastic particles can also end up in the soil where they accumulate due to their long decomposition time. In the air, it can be transported with other dust particles, and they can end up in the respiratory system. Besides clogging and irritation, it is hypothesized that microplastic particles are potential carriers for various microbes. Environmental and human health hazards are continuously under investigation.

The United Nations reported that a large amount of microplastics is generated in the building industry. Microplastics are released into the environment from plastic production, waste, cosmetic products, and many other sources. It has been reported that road traffic is also a contributor to microplastic pollution. It was reported that the largest contributor to this problem is the particle release from tyre wear. Road markings are also contributing to the problem due to road wear and exposure to the elements. The types of road marking material not only differ in composition but also in performance. Some are designed for an urban environment to withstand the abrasion of high-traffic areas; others are designed for high-speed roads with high visibility requirements in dark conditions etc. When applied freshly applied road markings do not contribute to microplastic pollution, but over their lifetime they can contribute to different levels depending on their usage and composition. This short study aims to conclude the current knowledge on secondary microplastics released from road markings in Scandinavia.

# 2. ROAD MARKING TYPES

There are different types of road markings. Their main distinctive feature lies in their purpose and their formulation. Generally, road markings are a mixture of plastic polymers, pigments, fillers, and additives. To provide the markings with retroreflection, glass beads are mixed into the road marking material and/or used as drop-on material directly on the surface at the time of application.

Depending on the composition road markings can be divided into several groups. The definition of the materials is according to the EN1871 standards and organized in the order of usage in Scandinavia.

### Thermoplastics

Hot applied or thermoplastic road markings are "*solvent-free marking products which are supplied in a block, granular, powder forms or performed (e.g. as tape), which is heated to a molten state prior to application to road surfaces, and which forms a cohesive film by cooling.*" (EN1871)

### Waterborne paints

These road markings are "*liquid products which contain binders, pigments, fillers, solvents, and additives, which can be supplied in single or multi-component systems and which, when applied, produces a cohesive film by the process of water evaporation or the process of water evaporation and a chemical reaction or coalescence process (in the case of water-based products).*" (EN1871)

### Solvent-borne paints

These road markings are "*liquid products which contain binders, pigments, fillers, solvents, and additives, which can be supplied in single or multi-component systems and which, when applied, produces a cohesive film by the process of solvent evaporation or the process of solvent evaporation and a chemical reaction or coalescence process (in the case of water-based products).*" (EN1871)

## Cold plastics

Cold plastics are "*viscous products supplied in multi-component forms (at least one main component and a hardener system), the cohesive film being formed after mixing of all components only by a chemical reaction following which the cold plastic becomes a solid*." (EN1871)

## Preformed road markings

"*Factory produced road marking system (or product), in sheet or roll form, capable of being applied to the substrate with adhesive, primer, pressure, heat or a combination of these."* (EN1790)

### Preformed thermoplastic road marking with/without drop-on materials

"*Preformed road marking made of thermoplastic road marking materials. Applied to the substrate by heating the material at melting temperature and with/without the addition of retroreflective and/or anti-skid materials during application."* (EN1790)

### Preformed cold plastic road markings

"*Preformed road marking made of cold plastic marking material. Applied to the substrate by means of an adhesive, while the photometric, colourimetry and skid resistance characteristics are not significantly modified during application."* (EN1790)

Tape

"*Preformed multilayer road marking, capable of adapting itself to the texture of the substrate, which may be precoated with pressure-sensitive adhesive, capable of being stuck to the substrate without heating the material, while the photometric, colourimetry and skid resistance characteristics are not significantly modified during application."* (EN1790)

# ROAD MARKING CERTIFICATION

The certification system helps achieve better performing higher quality materials applied on the roads. The certification document is based on well-defined and documented measurements of sample materials applied on public road test fields (Norway and Denmark) according to EN1824. The samples are tested by real-life traffic and weather conditions that are specific to the region. The certification process can include all types of road markings and the performance measurements are for one or two years. The performance is measured by the requirements concluded in Table 1.

Table 1: Requirements of road marking certification in Scandinavia

| REQUIREMENTS | DEFINITION |
|---|---|
| Coefficient of retroreflected luminance in dry ($R_L$) and wet ($R_{Lw}$) conditions | Retroreflection under vehicle headlamp illumination. |
| Luminance coefficient under diffuse illumination ($Q_d$) | Reflection in daylight. |
| Friction | The force resisting the relative motion between two surfaces that are sliding against each other. |
| Chromaticity coordinates, (x; y) | Describes the colour of the material. |

NordicCert is a certification for road marking materials led by VTI, Ramboll and the road authorities from Sweden, Denmark, Norway and Iceland. The certification level has increased continuously since being implemented by the authorities to ensure that contractors use the material with the longest lifetime which both increases the quality and decreases the environmental impact of the road marking. Using certified materials is a requirement in most Scandinavian contracts. The functional requirements of road marking in Denmark, Sweden and Norway are concluded in Table 2.

Table 2: Performance requirement values in Scandinavia

| PARAMETER | Type I White | Type II White | Hand applied White | Type I Yellow | Type II Yellow |
|---|---|---|---|---|---|
| $R_L$ [mcd/m²/lx] | ≥ 150 | ≥ 150 | ≥ 100 | ≥ 100 | ≥ 100 |
| $R_{Lw}$ [mcd/m²/lx] | - | ≥ 35 | - | - | ≥ 35 |
| $Q_d$ | ≥ 130 | ≥ 130 | ≥ 130 | ≥ 100 | ≥ 100 |
| Friction | ≥ 0,52 | ≥ 0,52 | ≥ 0,65 | ≥ 0,52 | ≥ 0,52 |
| Chromaticity coordinates, (x; y) | According to EN1436 | | | | |

## TYPES ON THE ROAD

Besides their compositions road markings can be grouped by the area of application as well. Depending on the position of the road marking is placed it can get different types and amounts of abrasion over its lifetime. This will influence how long and how well they can maintain their function. Table 3 concludes the types of applications.

Table 3: Types on the road

| APPLICATION TYPE | ROAD MARKING FORM (EXAMPLES) | EXPOSITION |
|---|---|---|
| **LONGITUDINAL** | Centre lines, lane markings and right edge lines | Normal traffic area |
| | Left edge lines | Low traffic area |
| **TRANSVERSAL** | Stop bars, crosswalks | High traffic area |
| | Traffic islands, bicycle lanes, gore areas | Low traffic area |
| **SPECIAL** | Arrows marking, text and symbols | Heavy traffic area |

Depending on the tyre roll over the road marking materials few areas must be differentiated. Cases, where there is a low amount of rollover happens, is generally referred to as low-traffic areas. These can be traffic islands, gore areas (exit and entry barriers) and bicycle lanes where the cycle path does not cross the road. In normal traffic areas, there is a higher rollover count, and most longitudinal road markings fall into this category. Although longitudinal marking, the left edge line usually falls into the low traffic category as it gets less rollover from tyres. High-traffic areas are urban areas or crossings that have the highest numbers of rollovers. These areas can be marked with transversal and other types of road markings (ex.: crosswalks or arrow markings).

Depending on the required functions the chemical composition of the road marking can change from road to road. In Scandinavia, the primary roads are marked with thermoplastic road markings. These materials are selected for their resistance and the ability to maintain their functional lifetime longer on the road surface. We assume that more than 80% of the applied road markings in this region are longitudinal markings.

# 3. THE SCANDINAVIAN MARKET

The roads in Scandinavia are similar to other European countries. The summer is mild in the region which is optimal for application and maintenance of the road markings. The industry faces the most challenges during the winter months. Road marking production, application and maintenance are stalled during the winter in Scandinavia. The cold weather requires materials that are developed specifically for this market.

Large area of this region is covered in snow and ice in winter. This requires continuous cleaning from the road authorities. The cleaning is mostly done by snowploughs that remove the large volume of snow from the road surface and treats the cleaned area with de-icing agent (usually some type of salt). The steel blade of the snowplough carves the snow and the ice and can cause major damage to the tarmac. Sometimes it is also possible to remove road markings as well, if the operator is not cautious or there is no protection used on the steel blade. The snow is ploughed to the side of the road in most cases. In urban areas the storage of removed snow is not possible due to the space limitations. In this case the snow is transported to snow dump sites, where the snow slowly melts leaving road dust behind. Fortunately dumping large volumes of snow into close water bodies (lakes and sea) are prohibited in most regions.

In great snowfall resource must be optimised and sometimes lower traffic road roads cannot be cleaned. These roads become icy as the temperature varies during the day and the night. This results in icy roads and traffic surfaces that are covered with compacted snow. To increase road safety in some areas it is highly recommended to use tyres with metal studs in them to increase grip on these surfaces. These studs are a huge challenge to this industry as it damages the road markings in case of a rollover. In addition to the abuse from the snowploughs. To combat the damaging effects thermoplastic road marking material used that is designed to provide the necessary performances under high wear. The pavement in high-traffic areas is also often polymer modified for increased durability.

The pavement is removed and recycled at the end of its lifetime. The road marking is recycled along with the asphalt and is converted into new asphalt, either by remixing on-site or at an asphalt plant. The removal of the pavement is determined by the lifetime of the asphalt and not the lifetime of the road marking so a road marking of high quality can be recycled before its lifetime has ended.

In low-traffic areas a layering effect occurs on the road markings. This layer-on-layer effect is caused be the reapplication which is determined by the loss of function and not the loss of material. The left edge line on the highway is a special case where there is close to no wear on the road marking. It's commonly repainted with waterborne paint due to this and in most places. There this layering effect is clearly visible. In these cases, the material is not emitting microplastics to the environment.

## ANNUAL AMOUNTS OF ROAD MARKINGS APPLIED

The data collection was initiated by the Scandinavian Road Marking Association. A data collection sheet was developed and sent out to the local contractors in each Scandinavian country. The contractors had four weeks to supply the necessary data about the yearly road marking applied in each country. In Norway, of the four contractors, only one supplied data to the association. The situation was similar in Sweden. In Denmark however, the data was collected directly from the local association, thus it covers all contractors. In the case of the previous two countries applied yearly amount was multiplied by the number of local contractors. This means four and three respectively. The collected data is presented in Table 4.

Table 4: The number of road markings applied annually in Scandinavia (tons/annum) [2021]

| ROAD MARKING | SWEDEN | NORWAY | DENMARK | SCANDINAVIA |
|---|---|---|---|---|
| **THERMOPLASTICS** | 15000 | 10660 | 5310 | **30970** |
| **WATERBORNE PAINTS** | 450 | 1344 | 30 | **2029** |
| **SOLVENT-BORNE PAINTS** | 30 | 20 | 290 | **340** |
| **COLD PLASTICS** | 90 | 40 | 30 | **160** |
| **PREFORMED MATERIALS** | 90 | 32 | 30 | **152** |
| **TOTAL ROAD MARKINGS APPLIED** | 15660 | 12096 | 5895 | **33651** |

## MARKET SHARE OF ROAD MARKING PRODUCTS IN SCANDINAVIA

Based on the collected data the market share of different road marking types was created. Table 5 shows that thermoplastic materials are dominating the Scandinavian market. The rest 8% is shared between the other four types of road markings, from which waterborne paints have the highest share percentage.

Table 5: Estimates market share of different road marking products in Scandinavia

| ROAD MARKING TYPE | MARKET SHARE | LONGITUDINAL | TRANSVERSAL OR SPECIAL |
|---|---|---|---|
| **THERMOPLASTICS** | 92,03% | 80% | 12% |
| **WATERBORNE PAINTS** | 6,03% | 100% | 0% |
| **SOLVENT-BORNE PAINTS** | 1,01% | 0% | 100% |
| **COLD PLASTICS** | 0,48% | 0% | 100% |
| **PREFORMED MATERIALS** | 0,45% | 0% | 100% |

## PRODUCT LIFE CYCLE

To better understand the pollution pathways of microplastic particles from road marking materials, the product life cycle has been analysed. Life cycle assessment is widely used to assess the environmental impacts of goods and services. In the construction industry, the EN 15804 standard is used to assess the different life cycle phases of a product. This standard can be applied to road marking materials as well. It will help better illustrate the pathways during the total life cycle of the product. Each life cycle phase will be extended with the commonly used processes in this region.

### A. Manufacturing

After reviewing the currently available legislation on the primary microplastic definition was assumed that. During the manufacturing process, there are no potential pathways for primary microplastic to leave the system. The secondary microplastic that might occur during production is considered marginal compared to the amounts released during the use phase.

### B. Use phase

**B1 – Application**

There are multiple options for this phase depending on the type of road marking. The most common type in Scandinavia is thermoplastics. These depending on the site can come in small bags (20kg) or in large, big bags of 500kg. The materials are melted in a gas or diesel-fuelled kettle and transferred into the application instrument.

After heating the thermoplastics are in liquid form, so they can be applied to the road surface. The second most used material in the region is waterborne paint is mainly delivered in fluid bags but also buckets. The paints are sprayed onto the road surface. Thus, it is impossible to emit either primary or secondary microplastics in this phase. After application, a layer of glass beads dropped on to the road marking surface. This layer is not only providing the road marking with the necessary functionality, but also acts as a protective layer.

As the preformed materials are in some cases brittle, a minimal amount of secondary microplastic can be emitted. These particles are assumed to stay in the packaging material which is always disposed of according to the local regulation. Therefore, it can be declared that the minimal amount of microplastics emitted never end up in the environment.

**B2 – Use**

The road markings' lifetime it determined by their ability to provide the required functions. During its lifetime the road marking experiences varying wear and tear that reduces the lifetime. This is highly dependent on the position of the road marking on the road. Longitudinal road markings are applied in normal traffic areas, where there is no low or excessive amount of tyre rollover is expected. During summer besides the abrasion from the rubber tyres and the UV radiation degrades the materials. The road requires winter maintenance in most parts of Scandinavia. Snowploughs and studded tyres cause increased damage and abrasion both to the road markings and the road surfaces. In case of rollover studded tyres can cause significant damage to longitudinal road markings, but due to their position on the road transversal road markings are exposed largely to these effects. In both cases the drop-on glass beads provide protection to the road markings to some extent.

**B3 – Reapplication**

Road markings must provide visibility and skid resistance throughout their lifetime. When one of these parameters cannot live up to the standards instead of removing the original road marking from the road surface, a new layer is applied on top. Depending on the type of material road marking type (Longitudinal vs transversal) this can happen every year, but in most cases, it only needs reapplication every 3-5 years.

The reapplication process is similar to the application process. A new layer of material with drop-on glass beads is applied of the old layer. Similar, to the application there are no microplastics released during this process. In Scandinavia, there are allowed maximum thicknesses of the road markings (typically 4mm) and if above, removals (see below) are required prior to reapplication.

**B4 – Replacement**

This is a specific scenario. Temporary markings can be applied during construction work to mark out work zones and alternative paths. These road marking tapes can be later removed from the road surface. Other times the complete replacement of the road markings happens either when the asphalt is removed completely, or if some changes need to be made in the traffic. These scenarios are described later in the Removal and recycling of the material chapter.

**B7 – Operational water use**

The operational water use applies only once in the case of road markings. In the case of thermoplastics sometimes water is used to cool down the road marking 5-10 seconds after the application. In this case, the thermoplastic materials are set by the temperature of the water. The particles (drop-on material) that might be washed down from the equipment can be released into the environment on the application site. It was assumed that the amount is minimal or even negligible.

There is one more case when water is used during operation. The application instrument must be cleaned every time it was used for waterborne paint application. In this case, the waterborne paint is washed in the application site, therefore releasing potential microplastic particles into the close environment of the road.

In both cases, even if there are microplastics released from the cleaning processes the amount is negligible even if we account for the whole region.

## C. End-of-life phase

As previously described the end of life of the road marking products highly depend on the lifetime of the road that they are applied to.

**C1. Destruction**

The destruction of road markings is highly connected to other processes. Although road marking materials are losing their function over time, the only time they get fully destroyed is when the surface they applied to – either the complete road or the asphalt – is removed for some reason. In Scandinavia, this process means most cases the road marking is recycled into the asphalt and applied somewhere else. The process of road works includes highly intrusive processes that cause dust in the work area. To some extent, this can lead to the release of microparticles. It was assumed the emission from this source is almost negligible.

**C2. Transport**

The destroyed road surface is generally loaded into a truck and transported to a recycling facility where the asphalt is remelted. In some cases, the remelt can be done locally. In both cases, it was assumed that the emission to the air is negligible compared to the total emissions.

**C3. Waste processing**

Waste processing in Scandinavia is highly focused on recycling. Most of the waste is treated either in a recycling facility (in the case of asphalt it is remelting) or in a waste-to-energy processing plant. In this case, the residues are treated according to local regulations. The incineration is mostly done by mixing various types of waste this type of treatment falls out of the scope of this study.

**C4. Disposal**

The legislation of waste disposal in Scandinavia is highly restricted by legislation. All members of the region progressively work on the reduction of landfills and focus on recycling waste. Even if the waste ends up in a landfill generally it is mixed with another type of construction waste. This source also falls out of the scope of this study.

## D. Removal and recycling of the material

**Removal**

In general road, markings are rarely removed from the road surface. Their function and their life cycle are extended by reapplying a new layer of road marking onto the old one. In some cases when the road markings are removed from the asphalt there are two main solutions used for that in this region. First, the road markings can be removed by a water jet system. Here the water is emitted with great pressure from a nozzle to the road surface removing the road marking that gets under this jet. The displaced water is then collected into a tank and filtered from the residue. The water can be reused, while the recovered road marking material can be disposed of according to local standards. Second, the road markings can be ground up from the road surface. In this case, as well the road dust is collected and disposed of properly.

**Recycling**

The recycling of road marking material is only possible in two ways. If the road marking is removed and the local waste management system prescribes, it can be used for waste-to-energy plants. Otherwise, there is a more cost-effective solution, and in Scandinavia, this solution is used more commonly. When the top layer of the road has to be replaced the asphalt is ground up together with the road markings on them. In some cases, the pavement milling instrument is grinding the surface and loads the material into trucks. The used asphalt is transported to a melting facility where the asphalt and the road markings in them are remelted and applied elsewhere. The other scenario, also common in the region is to locally grind up the road surface and melt it in place. After this process, the material is applied instantly back to the surface. This recycling path is possible as asphalt already contains elastomers (SBR or SBS rubber) and plastomers (LDPE or EVA). The polymer-modified asphalt is commonly used in the region as it provides improved durability and thermal resistance in cold temperatures (less cracking). When the recycled thermoplastic road marking is mixed with the asphalt the remelting process can increase the mentioned properties of the asphalt.

When the road marking material is recycled, they do not become road markings again, but part of the new asphalt. In both cases, the system is almost completely closed. The losses from the road markings that could become potentially secondary microplastic are negligible compared to other sources.

Table 6: Possibility of emission in each product category throughout the product life cycle
(*Some of the life cycle phases from the EN 15804 were modified to better suit the road marking products*)
[ '+'– possible pollution source; '0'– might pollute; '-'– no pollution]

| Manufacturing | | Use phase | | End-of-life and Benefits | |
|---|---|---|---|---|---|
| ***Product Stage*** | | ***Use stage*** | | ***End-of-Life Stage*** | |
| A1 | Raw materials | B1 | Application* | C1 | Demolition |
| A2 | Transport | B2 | Use* | C2 | Transport |
| A3 | Manufacturing | B3 | Reapplication* | C3 | Waste processing |
| ***Construction process*** | | B4 | Replacement | C4 | Disposal |
| A4 | Transport to site | B5 | Refurbishment | ***Benefits*** | |
| A5 | Installation | B6 | Operational energy use | D | Reuse/Recovery/Recycling |
| | | B7 | Operational water use | | |

| | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B7 | C1 | C2 | C3 | C4 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermoplastics | *0* | *0* | - | - | + | - | - | - | *0* | *0* | - | - | - |
| Waterborne | *0* | *0* | - | - | + | - | - | + | *0* | *0* | - | - | - |
| Solvent-borne | *0* | *0* | - | - | + | - | - | - | *0* | *0* | - | - | - |
| Cold plastics | *0* | *0* | - | - | + | - | - | - | *0* | *0* | - | - | - |
| Preformed | *0* | *0* | - | - | + | - | - | - | *0* | *0* | - | - | - |

Table 6 concludes the life cycle stage of road markings. The life cycle phases can have a high or a low probability of contributing to the emission of microplastics. In some cases, there is no chance that road markings can contribute. It was assumed that the potential contributors can be the manufacturing, the application, and the operational water use phase. The transportation to the site phase and the demolition and waste transport cases could pollute, but there is a lower probability in this case, or the amounts are marginal.

During the use phase – based on the currently available knowledge – it was assumed to have a high probability of contribution. Although it was not possible to estimate the amount only based on these findings. To estimate the potential amounts emitted yearly from the different road marking systems a simple model was developed.

# 4. MICROPLASTICS IN ROAD MARKING PRODUCTS

Microplastics raised a growing interest throughout many industries. The road marking industry is also involved in this as it is assumed that road markings also highly contribute to the systems. In some cases, this statement might be true, however, the available knowledge is limited on the topic. The assumptions and the findings must be reassessed.

## DEFINITION OF MICROPLASTICS

At the point of writing, there was no legislative consensus on the definition of secondary microplastics. A joint agreement was reached that the most updated version of EU legislation must be considered before a further investigation is done on the topic. It was first assumed that during the manufacturing process, road marking can contribute to the primary microplastic pollution as well. However, after carefully reviewing the relevant definition, our association decided to not include the manufacturing process in this study.

Regarding primary (or intentionally added) microplastics the ECHA Restriction states in paragraph 1 that polymers "*shall not [...] be placed on the market as a substance on its own or in a mixture as a microplastic in a concentration equal to or greater than 0.01% w/w…*" (ECHA 2019). But in paragraph 5 an exemption has been stated as" (b) *paragraph 1 shall not apply to placing on the market of substance or mixtures containing microplastics where physical properties of the microplastic are permanently modified during end use*" and "(*c*) *substances or mixtures containing microplastics where MP are permanently incorporated into a solid matrix during end use…*" (ECHA 2019). Therefore, the raw materials that are used to formulate road marking materials should not count as primary microplastics in any modelling scenario.

In case of the secondary microplastics, the definition is not so simple. A draft version (30/08/2022) of the upcoming legislation on secondary microplastics was submitted already by the European Commission. According to the draft of the legislation, secondary microplastics are: *"...polymers that are solid" contained in particles and constitute at least 1 % by weight of those particles build a continuous surface coating on particles, where at least 1 % by weight of those particles fulfil either of the following conditions: (1) all dimensions of the particle are* *equal to or less than 5 mm: or (2) the length of the particles is equal to or less than 15 mm and their length to diameter ratio is greater than 3 mm…".*In the proposal there are three derogations were added under section 5. Derogation 5a states that *"…synthetic polymer microparticles which are contained by technical means so that releases to the environment are prevented when used in accordance with the instructions for use during the intended end use."* While derogation 5b states *that "…synthetic polymer microparticles of which the physical properties are permanently modified during intended end use, in such a way that it no longer falls within the scope of the restriction."* The last derogation 5c states that *"…synthetic polymer microparticles which are permanently incorporated into a solid matrix during intended end use."*

Taking into consideration this definition a short review was done on the different road marking products and their production; it was found that several roads marking products will be exempted from the regulations. Other products can still contribute; therefore, the question remains: How much do these materials contribute? Looking into the Scandinavian reports that have had this problem as an objective, it is easy to see that the assumption of the emission amounts is rather a difficult task. To further investigate this question all the available reports on this topic in Scandinavia were carefully revised.

## Scandinavian reports on road marking microplastics

Reports regarding microplastic pollution related to road markings were collected. For this review only the publicly available reports have been considered, as they conclude nicely with the available knowledge on traffic-related microplastic emissions.

In Scandinavia, the published reports usually focus on tyre wear as the main source of traffic-related microplastics. Many highlights that vehicle tyre wear is the main contributor to traffic-related secondary microplastics. More and more studies report that the analysed samples contain large amounts of tyre-derived polymer particles. The estimation shows that the tyre wear particles annually contribute 61000 – 210000 tons of secondary microplastic in Europe. In Sweden, this was estimated to be 10000 tons per year. Swedish studies showed positive identification of high amounts of tyre-related particles in both water bodies and sediment samples as well. In Norway, it was estimated that tyre abrasion results in 4250 tons per year, while in Denmark it was assumed to be around 1900 tons per year. The Scandinavian traffic rules mandate the change of summer and winter tyres. The previous estimations do not include that in Sweden and Norway soft high-friction tyres can be also used which is hypothesised to be less wear resistance than the more rigid counterparties. The studded tyres are also excluded from these estimations, while these tyres are also prone to shed. Admittedly the magnitude of tyre-related microplastic particles is more severe, even though knowledge gaps are repeatedly emphasised in the available reports.

No reports investigate the topic of polymer-modified asphalts. Therefore, the extent of the contribution to the secondary microplastic emission remains unknown. The use of studded tyres can damage the road surface and the polymeric additives can be released from the asphalt. It is recommended that the issue unfolded while filling the knowledge gaps on the traffic-related particles.

All reports were carefully reviewed again with road markings in the scope, and the findings were concluded in Table 7. The first countries reporting on this topic were Norway and Denmark, while Sweden started investigating the issue a couple of years later. The geographical scopes differ in these studies. In most cases, the whole country was assessed, while in two cases they reported on the local urban area. The research in all cases focused on the microplastic emitted from road traffic. The studies concluded that road markings are also contributors to the issue. Some reports tried to assume the released amount, but their results usually operate with high uncertainties due to the lack of knowledge and the harmonized modelling methodologies. It means that we are unable to conclude the actual amounts of secondary microplastics emitted into the environment based on these studies.

Table 7: The concluded assumption of road marking microplastics-related reports from Scandinavia

| REPORT | LOCATION | | ESTIMATION [tons/year] |
|---|---|---|---|
| **VTI (Andersson-Sköld et al. 2020)** | *SE* | *Country* | *0* |
| **IVL (Magnusson et al. 2017)** | *SE* | *Country* | *504* |
| **Göteborg stad (Magnusson et al. 2019)** | *SE* | *City* | *20* |
| **Stockholm stad (Azzopardi et al. 2019)** | *SE* | *City* | *15 – 30* |
| **TØI (Vogelsang et al. 2019)** | *NO* | *Country* | *90 – 180* |
| **Miljödirektoratet (Sundt, Schulze, and Syversen 2014)** | *NO* | *Country* | *320* |
| **DTU (Lassen et al. 2015)** | *DK* | *Country* | *110 – 690* |

## Challenges

Reviewing the reports also highlighted some challenges on why it is difficult to make assumptions on the topic. The concern regarding microplastic pollution has been reported many years ago. While it has been proven that road markings are contributing to the issue, as they are applied horizontally and to provide their function they will consequently wear off by vehicular traffic. The scientific knowledge is very limited on the topic of road marking microplastics. Even though it is part of the problem, road markings are a **necessary and mandatory component to safe road traffic** and road marking presence is widespread.

The pollution pathways of microplastics released from road markings are similar to other sources of microplastics. First, road dust is emitted **into the air**. When cars pass by the road dust is caught up by the turbulent air or wind and settles into the near environment and onto the chassis of the vehicles. Second, t**o water,** these particles can be emitted as the rain washes off the vehicles. Furthermore, rain creates road run-off water that washes the particles to the nearby waterbodies. Finally, **to the soil** of roadside ditches where all the previously mentioned mechanisms contribute. When emitted to these environmental matrices the particles can travel freely or accumulate. The challenge is to find a **harmonized sampling and analysis method** and **define the source** of the material for the different environmental matrices.

Finding a standardized method for sampling and sample preparation is exceptionally hard because all matrices have different physical and chemical properties. Some of them are cleaner (like drinking water) and allow easier access to the target particles and the samples require less preparation. Others (like soil or sediment) require more thorough cleaning and extensive preparations. The challenge to achieving a harmonized methodology is to **reduce particle loss** during preparation as well as **reduce the cost** to make it more accessible. These can improve data collection by reducing uncertainties and collecting more data.

The environmental samples are usually **analysed** either **visually by stereomicroscope**, with **Fourier-transformation spectroscopy** (FTIR), or **gas chromatography mass-spectrometry** (usually pyrolysis GC-MS). The stereomicroscope method is usually the most readily available. Its execution does not require highly trained staff, but the reported results highly rely on subjective assumptions. The FTIR analysis method is time-consuming and requires highly trained operators. It reports in particle number which is usually paired with the sample volume. The py-GCMS method is somewhat faster, but still requires trained professionals for operation. This method gives results in mass which is paired with the volume of the taken sample. Besides these methodologies, there are other ongoing developments that further increase the challenge of finding a scientific consensus on the **reported amounts**. When the results of these analysis are better harmonized the uncertainty of the assumptions made on the source and the emitted microplastic amounts can be reduced.

The **human and environmental health effects** are far from understood. Besides the lack of consistent and harmonized data makes the evaluation of the knowledge even harder. To better understand the problem, when upcoming reports address this issue in detail they will be reviewed and assessed.

## Conclusions on the review

The reports assume that either all or a high percentage of road marking is degraded over time, and they end up as secondary microplastics in the environment. While the degradation to some extent is true, these reports have failed to consider a few key parameters that are quite important over the lifetime of road marking products.

- When applied road marking materials are protected by drop-on material, and until it loses this protective layer the road marking will stay intact and not release microplastic material. When the necessary performance is below a threshold value (retroreflection, skid resistance etc) the road marking must be renewed with another layer of material (build-up of layers).

- Road markings can be removed by high-pressure waterjet or a grinder. Each technology offers a closed system solution where the road marking material is recycled.
- In many cases road marking is still present on the surface when the pavement is recycled.

These points support the hypothesis that it is impossible that 100% of the road markings end up as secondary microplastics when their life cycle is over. To correctly estimate the amounts of road marking microplastics these scenarios must be addressed and evaluated.

## ESTIMATED MATERIAL LOSS DURING USE PHASE

As previous models and estimations did not include any, an attempt was made in collaboration with other road marking associations to correctly estimate the potential loss of the annually applied road markings. The model includes all the wear parameters that previous studies did not. As well as it is based on data directly derived from the local contractors in the region.

After the road marking is applied to the traffic surface, in most cases drop-on material is used to achieve the initial performance. Also, the glass beads provide protection for the road marking from physical degradation increasing the functional lifetime of the product. Depending on the type of road marking the rate of degradation, and thus, the functional lifetime varies from one and a half to five years. After the functional lifetime is exhausted it does not mean the road marking is completely gone from the road surface. It only means that it is unable to provide the performance (visibility and skid resistance). Common practice and it is mandatory in the region to renew the road markings that lost their functions. The renewal process can be done over and over until the traffic surface is changed. These parameters are crucial to correctly evaluate and estimate the number of microplastics emitted from the road markings, and from previous studies, it was excluded.

The data for the model has been provided by different sources. The technical parameters such as solid content, dosage, and the amounts of premix glass beads and drop-on glass beads were supported by industry experts and an average was derived for each type of road marking. In addition to this, the functional durability of the road markings was estimated by industry experts in the region. The data provided in our market research was used to describe the amount of road marking applied yearly in Scandinavia.

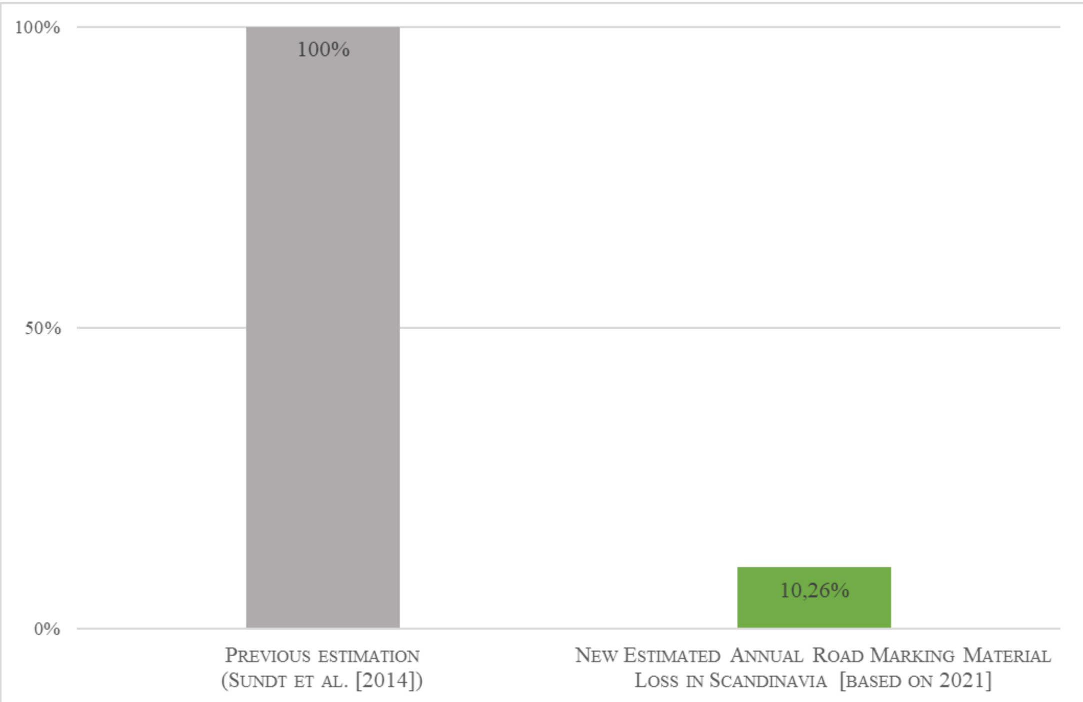


Figure 1: Estimation of annual material loss of road markings [%]

Figure 1 shows the estimation of annual material loss of road markings [%]. Sundt *et al.* (2014) did not include the functional lifetime; thus, it was assumed 100 % of the applied road marking material is gone by the end of the year. As previously described, functional lifetime is key to estimate the loss, because it does not got removed by the end of this but rather reapplied. The estimation model includes this key principal and all the contributing physical parameters as well. Based on the local contractors' data and our model it was assumed that the annual road marking material loss (excluding glass beads) is only 10,26 % of all the 33651 tons of applied road marking material in Norway, Sweden and Denmark combined.

The most used material in Scandinavia is thermoplastic. Even though the main application is longitudinal edge and centre lines there are a lot of preformed materials that are applied in high-traffic areas. This type of road marking maintains its functional life for up to four and a half years. It can achieve this because after the drop-on glass beads are shed from its surface the premix glass beads can maintain their function.

The second most used type of road marking in the region is waterborne paint. These are mostly used on secondary roads, where there is less traffic. Water bond paints are less resistant to wear, and they have a low 1,5 years of functional life. Therefore, the emission ratio is higher in this case.

The least used materials in this region are solvent-borne and cold plastics. In Scandinavia, solvent-borne paints are mostly used in parking areas. Where cold plastics are mainly used as coloured areas. While these have a high functional lifetime, these areas fall in the high traffic areas therefore wear of these material is relatively high.

# Discussion

There are multiple challenges in the case of reporting on road marking materials. Our association hypothesis is that these difficulties are derived from the lack of consistency in the legislation on the definition of microplastic particles. Also due to the challenges of microplastic analysis, it is hard to find a strong basis for estimation in the field. This is backed by the fact that most of the time road marking materials are reported together with the abrasion of car tyres.

Legislation is seeming to form to regulate the various microplastic emissions. However, the proposals for the new chemical definition of primary and secondary microplastics seems to neglect the fact that not all industry use polymers the same way. In the case of road markings, the filler material has the highest percentage in the formulation of the materials. Whereas the polymer binder is only used in smaller amounts to hold the filler materials together and give consistency to the product. This fact was also neglected in previous studies where the amounts were estimated from the road marking materials.

It was reported previously that there is a lack of adequate chemical analysis methods when it comes to road marking-related microplastics. It is assumed to derive from two main reasons. The first is analysing microplastics requires a new sample collection and preparation method in almost every new analysed media. Developing these is quite costly, and the tendency in the scientific community shows that topics closely related to human health have been a priority in recent years.

Currently only a handful of study available that tries to estimate the pollution amount correctly. These studies tend to involve industry experts, but still lack analysis methods to properly quantify the findings. Currently, only one new study was able to detect and differentiate properly road marking particles in road dust. It was reported that only a fraction (around 1,1%) (Järlskog et al. 2022) of the analysed particles related to road markings. This article suggests that the amount estimated in further studies is false and not all applied road marking end up as secondary microplastic in the environment. The findings in research papers support our estimation as well, where based on the total applied road marking amounts and their loss (excluding glass beads) is 10,26%.

# Conclusion

Microplastic pollution is a serious issue that must be further explored in the future. Although Scandinavia is progressive in this direction, it was noted that the previous assumptions are based on false assumptions. The lack of harmonization and the confusion about the road marking systems further the confusion in the scientific community. This paired with the lack of consultation with industry partners resulted in a false estimation of potential microplastic emissions.

Our report introduces the reader to the road marking materials in a structured manner. An overview of the Scandinavian market was established based on industry collaboration, where local contractors were given correct estimates on the applied road marking amount in the region.

Based on the reviewed reports it was noted that neither the definition of the road markings nor the lifecycle of these materials was unclear. According to the EN15804 standards, the life cycle stage of road markings has to be analysed and assumptions were made in which stages of these materials are able to contribute to the emissions. In collaboration with other road marking associations in Europe based on these life cycle stages; a model was developed to correctly estimate the amount of yearly road marking degradation. It was estimated that only 10,26% of material got loss (excluding glass beads) in the whole region annually. This is a significantly lower amount compared to previous estimations.

It is highly recommended that the investigation of road marking-related studies in the future involve consultation with industry experts. Furthermore, to instantaneously reduce the potential emissions of microplastics, it is highly recommended to improve the standards on the reapplication process as the drop-on glass beads protect the road marking surface from potential wear. In Scandinavia, it is now that winter maintenance and studded tyres have a negative effect on road markings. It is recommended to investigate potential technologies that can help protect the road markings on the road surfaces (inlaid road markings).

Finally, further investigation of this topic must be conducted in the future as it can increase understanding of potential pollution mechanisms and also help the industry to improve the road marking products on the market.

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# APPENDIX

| Country | Year | Author | Title | Conclusion | Amount estimates |
|---|---|---|---|---|---|
| **Sweden** | 2020 | VTI (Andersson-Sköld et al. 2020) | Mikroplast från däck- och vägslitage | There are no standardized methods for sampling and analysing particles caused by wear and tear on the road. Estimates that 3.7 % of microplastics from roads and tires are from road markings. Further studies to learn about road markings' wear and tear are needed. Suggests that inlaid road markings can reduce wear and tear on road markings and microplastic emissions | No estimates. The report is only a conclusion of what VTI knows about microplastics from roads and tyres |
| **Sweden** | 2017 | IVL (Magnusson et al. 2017) | Swedish sources and pathways for microplastics to the marine environment | Estimations based on (Sundt, Schulze, and Syversen 2014), which base assumptions on the road length network. | 8190 tons/year from road wear and abrasion of tyres. |
| **Sweden** | 2019 | Göteborg stad (Magnusson et al. 2019) | Förekomst och spridning av mikroplast, gummi och asfaltspartiklar från vägtrafik | Numbers are based on previous reports, most likely assumes 100 % emission of microplastics from road marking. Probably only considers the polymers as microplastics | 20 tons/year from road markings in Gothenburg |
| **Sweden** | 2019 | Stockholm stad (Azzopardi et al. 2019) | Handlingsplan för minskad spridning av mikroplast | Assumed to be a medium contributor of microplastics in Stockholm, although the uncertainty is also considered medium. Data reported by IVL in 2018. Only polymers are considered to be microplastics, assuming 2-4 % of road marking to be polymers | 15-30 tons/year from road markings in Stockholm |
| **Norway** | 2019 | TØI (Vogelsang et al. 2019) | Microplastic in road dust | Focus on road dust. The study assumes that only thermoplastics and elastomers contribute to microplastic pollution from road dust. It evaluates methods for the removal of microplastics from road runoff water and tunnel wash water. | 90-180 tons/year of thermoplastics and elastomers from road markings to air |

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|---|---|---|---|---|---|
| **Norway** | 2014 | Miljödirektoratet<br>(Sundt, Schulze, and Syversen 2014) | Sources of microplastic pollution to the marine environment | Assumes 100 % emission of microplastics from road marking. Only considers the polymers as microplastics | 320 tons/year from road markings in Norway |
| **Denmark** | 2015 | DTU<br>(Lassen et al. 2015) | Microplastics - Occurrence, effects, and sources of releases to the environment in Denmark | It was assumed that 100% of the used materials used for different roadmaking products are released to the environment in form of secondary microplastic | 10-18ton/year to water, 60-150 tons/year to roadside soil, 6-80 tons/year to agricultural soil |