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# Sea-based sources of microplastics to the Norwegian marine environment

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Summary

This report is an update of data available on primary and secondary discharges of microplastics from sea-based sources to the Norwegian marine environment. Nine broad potential sea-based source categories are relevant to the Norwegian marine environment. These include maritime coatings, maritime traffic, ports marinas and shipyards, decommissioning activities, land-based industry (with discharged into the marine environment), fisheries, aquaculture, petroleum-related activities, and other offshore activities. Sources of primary microplastics can be linked production sites for plastics and paints which have discharges to the sea, or maintenance facilities in coastal areas. Petroleum activities also have discharges of primary microplastics to the ocean. Secondary microplastics can be derived from maintenance, decommissioning and wear and tear across various maritime sectors as well as the breakdown of large plastic items lost or discarded at sea. There is surprisingly little information on the quantities of microplastics released into ocean from coastal or other sea-based sources. Few of the source categories have some information available, and the certainty around the data for all source categories was classed as medium or low. This makes validating emissions values and interpreting the data challenging. As there is little certainty behind the available data, no sea-base source was identified as the biggest contributor. Future research must focus on obtaining comparable empirical data across all potential source categories. This includes calculations of emissions based on actual reported discharge values and comparative environmental investigations. The relative size of the sector may play a role and this should be investigated further.

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# Sea-based sources of microplastics to the Norwegian marine environment

# Preface

This report presents the outcome from the project *Utslipp av mikroplast fra sjøbaserte kilder i Norge* (Sea-based sources of microplastics). This project has been run in agreement between Miljødirektoratet as client and NIVA as project manager. The client's contact has been Kine Martinsen. Project leader at NIVA has been Amy Lusher. The project from inception to reporting was carried out by Amy Lusher and Ragnhild Pettersen at Akvaplan-niva. The report was written with support from Inger Lise Nerland Bråte, Morten Jartun, Marianne Olsen (NIVA) and Claudia Halsband (Akvaplan-niva). Marianne Olsen carried out QA of the report. Jonny Beyer (NIVA) and Andy Booth (SINTEF) are thanked for fruitful discussions. NIVA appreciates the opportunity to complete this project and acknowledges everyone involved for good cooperation.

Oslo, December 2020

Amy Lusher
*Project Manager*

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# Summary

Norway has recognized the challenges in combating marine plastic litter for several years. In order to implement effective fact-based remediation actions, it is essential to have the most up-to-date overview of the sources of plastic litter and good knowledge of their pathways and fate in the environment, including those with aquatic origin. Plastic litter can roughly be divided into three size groups: macroplastics (> 5 mm), microplastics (0.001 – 5 mm) and nanoplastics (< 0.001 mm). This report only addresses microplastic. The size range described here (0.001 – 5 mm) is in accordance with the definition made by UN's Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP, 2019). Plastic polymers are often associated with additive chemicals which are used, for example, to increase UV resistance, reduce flammability, impart colours and other desirable properties. These chemicals can have consequences for the environment and knowledge of the chemical composition of plastics as well as their assessment under REACH[1] regulations can elucidate the scale of impact related to each plastic source.

A first national investigation of the sources of microplastics to the Norwegian environment was compiled in 2014 (Sundt et al., 2014). This study noted many gaps in knowledge, with emphasis on the quantification of the types and amounts of microplastics, derived from the breakdown of macroplastic debris in the ocean. The current report presents an update of data available for the current situation in Norway, focusing on *primary* and *secondary* discharges of microplastics from sea-based sources. It takes into consideration their quantity and composition as well as pathways, distribution and fate in the environment, including the degradation of microplastics during their use and following their release into the environment.

Nine broad potential sea-based source categories are relevant to the Norwegian marine environment. These include maritime coatings (which have been defined as a cross-sectoral source), maritime traffic, ports marinas and shipyards, decommissioning activities, land-based industry (with discharged into the marine environment), fisheries, aquaculture, petroleum-related activities, and other offshore activities. This report found that identifying the potential sources of primary microplastics was less complicated as sources could be identified, even when emissions were not available obtainable. Sources of primary microplastics can be linked production sites for plastics and paints which have discharges to the sea, or maintenance facilities in coastal areas. Petroleum activities also have discharges of primary microplastics to the ocean. Secondary microplastics could be derived from maintenance, decommissioning and wear and tear across various maritime sectors as well as the breakdown of large plastic items lost or discarded at sea.

There is surprisingly little information on the quantities of microplastics released into ocean from coastal or other sea-based sources. Few of the source categories have some information available, and the certainty around the data for all source categories was classed as medium or low. There are few field reports on the quantities of microplastics found in the Norwegian environment, including polymer types, size and associated additives. This makes validating emissions values and interpreting the data challenging. As there is little certainty behind the available data, no sea-base source was identified as the biggest contributor. The relative size of the sector should be investigated further.

Future research must focus on obtaining comparable empirical data across all potential source categories. This includes calculations of emissions based on actual reported discharge values and comparative environmental investigations.

[1] See https://ec.europa.eu/environment/chemicals/reach/reach_en.htm

# Sammendrag

Tittel: Utslipp av mikroplast fra sjøbaserte kilder i Norge
Forfatter(e): Amy L. Lusher, Ragnhild Pettersen
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Utfordringen med å bekjempe marint plastavfall har vært anerkjent av Norge i mange år. For å iverksette effektive faktabaserte tiltak, er det viktig å ha den mest oppdaterte oversikten over kildene til plastsøppel og god kunnskap om deres transportveier og skjebne i miljøet, inkludert de med akvatisk opprinnelse. Plastavfall kan grovt sett deles inn i tre størrelsesgrupper: makroplast (> 5 mm), mikroplast (0,001 – 5 mm) og nanoplast (<0,001 mm). Denne rapporten omtaler kun mikroplast. Størrelsesområdet som er beskrevet her (0,001 – 5 mm) er i samsvar med definisjonen som ble gjort av FNs "Group of Experts on the Scientific Aspects of Marine Environmental Protection" (GESAMP, 2019). Plastpolymerer er ofte assosiert med kjemikalier som blir tilsatt for å oppnå ønskede egenskaper, for eksempel å øke UV-motstand, redusere brennbarhet, tilsette farger o.l. Disse kjemikaliene kan ha konsekvenser for miljøet og kunnskapen om den kjemiske sammensetningen av plast, samt vurderingen av dem i henhold til REACH-regelverket kan belyse omfanget av påvirkning knyttet til hver plastkilde.

En første nasjonal undersøkelse av kildene til mikroplast i det norske miljøet ble samlet i 2014 (Sundt m.fl. 2014). Denne studien identifiserte flere kunnskapshull, hvor hovedvekten var på kvantifisering av typer og mengder mikroplast som stammer fra nedbrytningen av makroplast i havet. Denne rapporten presenterer en oppdatering av tilgjengelige data for den nåværende situasjonen i Norge, med fokus på primære og sekundære utslipp av mikroplast fra havbaserte kilder. Rapporten omhandler sammensetning av plast, mengde plast som slippes ut og finner veien til det marine miljøet og hvordan den så distribueres og hvor den til slutt ender opp samt nedbryting av mikroplast under bruk og etter frigjøring i det marine miljø.

Ni potensielle havbaserte kilder er relevante for det norske havmiljøet. Disse inkluderer marin maling (som er definert som en kilde til mikroplast i flere sektorer), sjøfart, havner og verft, opphugging/avviklings aktiviteter, landbasert industri med utslipp i det marine miljøet, fiskeri, havbruk, petroleumsrelaterte aktiviteter og andre aktiviteter offshore Denne rapporten viser at potensielle kilder til primær mikroplast lar seg identifisere selv når selve utslippet ikke er tilgjengelig. Kilder til primær mikroplast kan knyttes til produksjonssteder for plast og maling som har utslipp til det marine miljøet, og områder langs kysten hvor det utføres vedlikeholdsarbeid. Petroleumsrelaterte aktiviteter har også utslipp av primær mikroplast til det marine miljø. Sekundær mikroplast kan stamme fra vedlikehold, opphugging/avvikling samt slitasje og bruk i flere av de identifiserte kildene i tillegg til nedbryting av store plastgjenstander som er tapt eller kastes i sjøen.

Det er overraskende lite informasjon om mengden mikroplast som slippes ut i havet fra kystnære eller andre havbaserte kilder. Det er få kilder som har noe tilgjengelig informasjon, og påliteligheten til dataene for alle kildene ble klassifisert som middels eller lav. Det er få feltrapporter om mengdene av mikroplast i det norske miljøet – inkludert informasjon om polymertyper, størrelse og tilknyttede tilsetningsstoffer – det er derfor utfordrende å skaffe pålitelige, faktabaserte tall for utslipp og tolke tilgjengelige data på en god måte. Siden det er store usikkerheter bak tilgjengelige data, ble ingen havbaserte kilder identifisert som store bidragsytere. Den relative størrelsen på kildesektoren bør derfor undersøkes nærmere. Fremtidig forskning bør fokusere på innhenting av sammenlignbare empiriske data på tvers av alle potensielle kilder. Dette inkluderer beregninger av utslipp basert på faktisk rapporterte utslippsverdier og sammenlignende miljøundersøkelser.

# 0 Glossary

| | |
|---|---|
| **Common plastics and plastic polymers** | |
| ABS | Acrylonitrile butadiene styrene |
| AC | Acrylic |
| EPDM | Ethylene propylene diene monomer |
| EPS | Expanded polystyrene |
| EVA | Ethylene vinyl acetate |
| EPS | Expanded polystyrene |
| FRP | Fibre reinforced plastic |
| HIPS | High impact polystyrene |
| HD-PE | High density polyethylene |
| LD-PE | Low density polyethylene |
| PA | Polyamide 4, 5, 6, 11, 66 |
| PC | Polycarbonate |
| PE | Polyethylene |
| PET | Polyethylene terephthalate |
| PGA | Polyglycolic acid |
| PLA | Polylactic acid |
| PMMA | Polymethyl methacrylate |
| PP | Polypropylene |
| PS | (Expanded) polystyrene |
| PTFE | Polytetrafluoroethylene |
| PUR | Polyurethane |
| PUD | Polyurethane dispersion |
| PVA | Polyvinyl alcohol |
| PVC | Polyvinyl chloride |
| PVDF | Polyvinylidene fluoride |
| SBR | Styrene-butadiene rubber |
| TPE | Thermoplastic elastomers |
| XPS | Extruded polystyrene |
| **Common chemical additives in plastic** | |
| BBP | Benzyl butyl phthalate |
| BPA | Bisphenol A |
| CDPs | Controlled Depletion Polymers |
| DBP | Dibutyl phthalate |
| DCHP | Dicyclohexyl phthalate |
| DEP | Diethyl phthalate |
| DEHP | Di-(2-ethylhexyl) phthalate |
| DHA | Di-heptyl adipate |
| HAD | Heptyl adipate |
| HBCDD | Hexabromocyclododecane |
| NP | Nonylphenol |
| PAHs | Polyaromatic hydrocarbons |
| PBDEs | Polybrominated diphenyl ethers (penta, octa & deca forms) |
| PCBs | Polychlorinated biphenyls |
| PFOA | Perfluorooctanoic acid |
| Phthalates | Phthalate esters |
| SPCs | Self-Polishing Copolymers |
| TBT | Tributyl tin |
| TCEP | Tris(2-chloroethyl) phosphate |

| **Other abbreviations** | |
|---|---|
| ALDFG | Abandoned, lost and otherwise discarded fishing gear |
| ASC | Aquaculture Stewardship Council |
| CLP | Classification, labelling and packaging |
| EDC | Endocrine disrupting chemical |
| EEZ | Exclusive economic zone |
| EU | European Union |
| HME | Hazardous to the marine environment |
| PBT | Persistence, Bioaccumulative and Toxic |
| RAS | Recirculating aquaculture systems |
| vPvB | Very persistent, very bioaccumulative, |
| UV | Ultraviolet |
| WWTP | Wastewater treatment plant |
| **Organisations** | |
| ACC | American Chemical Council |
| ECHA | European Chemicals Agency |
| EFTA | European Free Trade Association |
| EOSCA | European Oilfield Chemical Speciality Association |
| FAO | Food and Agricultural Organisation of the United Nations |
| GESAMP | Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection |
| IMO | International Maritime Organisation |
| IUCN | International Union for Conservation of Nature |
| MARPOL | International Convention for the Prevention of Pollution from Ships |
| MEPC | Marine Environment Protection Committee |
| OCED | Organisation for Economic Co-operation and Development |
| REACH | Registration, Evaluation, Authorisation and Restriction of Chemicals |
| WFD | Water Framework Directive |
| WSC | World Shipping Council |

# 1 Introduction

## 1.1 Background, aim and scope

The concern for plastic contamination is rapidly evolving. There has been huge international effort focused towards developing methods and establishing monitoring frameworks in the marine environment. This is mirrored in Norway's national strategy[2]. However, the focus has mainly been on documenting the presence and abundance of microplastics in environmental compartments and matrices, and not so much on the inputs and the identification of sources and pathways. Hence, major uncertainties still exist that relate to quantities of plastic input, especially in the case of microplastics derived from the breakdown of larger items (secondary microplastics). Plastic particles are characterized not only by size, but also by morphology, polymer type and additives (ECHA, 2018). These properties have significant impact on their characteristics with respect to density, affinity to other materials and resistance to degradation. All of which impact their fate in the environment. It is a challenge to routinely identify microplastics in environmental samples, and even more so, identifying their source. Considerable progress has been made in the last five years in developing quality assured and controlled analytical procedures and monitoring routines, leading to more reliable and representative data. Yet, there is still little improvement in source identification.

Sea-based activities and industries may contribute to the global burden of marine litter. These warrant concern as synthetic materials are significant components of marine litter including those generated from fishing, aquaculture, shipping, ocean dumping and other maritime and offshore activities (GESAMP, 2020). The first nationwide study to summarize the sources, pathways and fate of microplastics in Norway (Sundt et al., 2014) was followed by similar studies in Denmark (Lassen et al., 2015), Sweden (Magnusson et al., 2016) and later at a European scale (Hann et al., 2018). All reports have highlighted many uncertainties, not only in the accuracy of plastic abundance estimates but also in specifying and quantifying sources, pathways and eventual fate in the environment. Sundt et al. (2014) characterized sea- and land-based sources of microplastic through estimates of emissions and a mass-flow approach for Norway. When considering microplastics of primary origin, the report estimated about 8 000 tonnes in annual discharge. It was not possible to make an estimate for microplastic of secondary origin. The report estimated that microplastics from the use (wear and tear) of fisheries and aquaculture equipment could be between 1 000 and 10 000 tonnes a year. The report concluded that it was important to obtain more information, and it called for industries to take an active part in providing data for future estimations. Although there has not been a comprehensive update of microplastic sources to the Norwegian environment since this report was published, there have been some attempts to quantify the releases from some sea-based sources (Haave et al., 2019; Gomeiro et al., 2020), the proportional representation of different categories of macroplastics on beaches (e.g. Haarr et al., 2020; Falk-Andersson and Strietman, 2019; Falk-Andersson et al., 2019), as well as the distribution, degradation mechanisms and transport of microplastics in the marine environment (Booth et al., 2017).

Similar assessments have been made internationally. EUNOMIA (Hann et al., 2018) published a report concerning microplastics that are created during a product lifecycle through wear and tear or emitted through accidental spills. This was in parallel to a report by Amec Foster Wheeler Environment & Infrastructure UK Limited (2017) which focused on microplastics that are intentionally added as an

[2] See https://www.regjeringen.no/en/dokumenter/meld.-st.-35-20162017/id2547988/?ch=4

ingredient to a product. Both these reports were produced for the European Commission (DG Environment). The main take-home messages from these parallel reports were that:

- Tyre wear, weathering of road markings, spills of pre-production pellets and effluents from the washing of synthetic textiles are all significant sources of microplastic emissions.

- Only a proportion of microplastic emissions from terrestrial sources reach the aquatic environment.

With the Norwegian national assessment as the primary background (i.e. Sundt et al., 2014), supported by the international status of microplastics in fisheries and aquaculture (Lusher et al., 2017; Lusher and Welden, 2020), and other sea-based sources (GESAMP, 2020), this report will provide an update of the information already presented there, and supplement it with information on other known or suspected sources identified in recent national and international literature, or by expert judgement. Hence, this approach will target the stages of the product life cycle which sees the release of microplastics into the sea, whilst validating previous estimates with the current state of knowledge regarding sources and environmental data. This update is focused on potential sea-based sources, especially including maritime coatings, maritime traffic, ports and marinas, decommissioning of ships and offshore infrastructure, discharges from land-based industry (with direct discharges to the sea) and, discharges from coastal and offshore industries (fisheries, aquaculture, petroleum and others). It does not consider sources from the terrestrial and freshwater environment. Implications for biota are not included as they are outside the remit of this assignment.

## 1.2 Definitions

### 1.2.1 Size and materials

Plastic litter can roughly be divided into three size groups: macroplastics (> 5 mm), microplastics (0.001 – 5 mm) and nanoplastics (< 0.001 mm). This assignment will address only microplastics. The size range 0.001 – 5 mm is in accordance with the definition made by UN's Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP, 2019).

### 1.2.2 Emission vs. source

**Microplastic sources**: the generation of microplastic from known source (sector, industry or activity).

**Microplastic emissions**: the amount of microplastics that are emitted from a source to the marine environment.

### 1.2.3 Primary and secondary classification

**Primary microplastics** are those which are manufactured in small sizes for specific purposes. These include flocculants used in petroleum activities and plastic pellets representing raw material for further production of plastic products.

**Secondary microplastics** are those generated through the wear and tear of in-use macroplastic materials as well as the breakdown products of macroplastics. These include fibres generated from the use of fishing gear, the degradation products of abandoned, lost and otherwise discarded fishing gear (ALDFG), and fibres from textiles released through effluents.

## 1.3 Additives associated with plastic

Plastic additives are chemical compounds added to plastics during manufacture. Importantly, they are not chemically bound (unless they are polymerised to become part of the polymer chain, Hahladakis et al., 2018). Additives are used to modify the resin features by either enhancing desired plastic characteristics or reducing unwanted properties (Murphy, 2001). These chemical compounds provide required properties to a plastic polymer or are incorporated to facilitate the manufacturing process (OECD, 2004). Additives can be characterised by their functional and structural components into four major classes: functional additives, colorants, fillers and reinforcements (**Figure 1**):

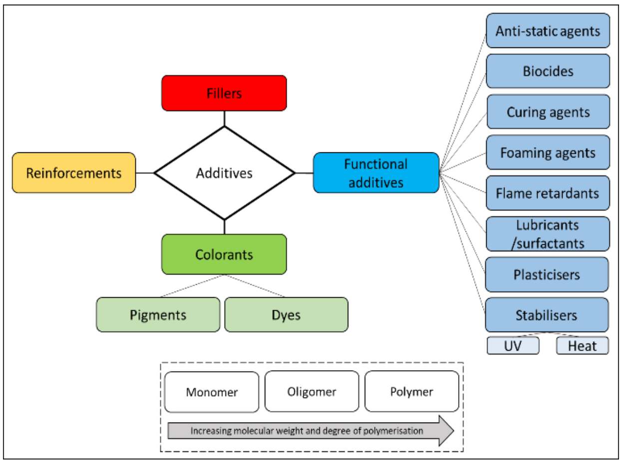


**Figure 1. Plastic additives adapted from Gunaalan et al. (2020) and Hansen et al. (2013).**

- **Functional additives** – substances designed to modify the physicochemical properties of polymers.
- **Colorants** – provide colour and are widely used in consumer products and textiles.
- **Fillers** – improve polymer coating properties.
- **Reinforcements** (stabilisers) – increase mechanical resistance.

Plastic additives are mainly used as plasticizers, flame retardants, stabilizers, antioxidants and pigments. The type of additive used depends on the polymer and the requirements of the final product (**Table 1**). Some plastic additives have dual uses, for example Bisphenol A (BPA) – is used as a monomer of polycarbonate (PC) but also as a stabilizer in other polymers. Most additives represent a low percentage weight of a polymer (such as biocides, anti-statics, colorants) whereas others, such as plasticisers can comprise up to 70% of the polymer weight (Andrady and Rajapakse, 2016).

Unfortunately, many plastic additives are hazardous substances – "*Chemicals that pose a risk to the environment and human health*", as defined by the REACH regulation in the European Union (EU) according to the European Chemical Agency (ECHA, 2019). A recent assessment of an extensive list of chemicals likely used in plastic packaging (n = 906), identified 63 which rank highest as human health hazards, and 68 as environmental hazards according to the EU regulation on Classification, Labelling and Packaging (CLP) of substances and mixtures (Groh et al., 2019). Seven chemicals were classified as persistent, bioaccumulative and toxic (PBT) or very persistent, very bioaccumulative (vPvB), and 15 as endocrine disrupting chemicals (EDC). Many of the hazardous chemicals are used in plastics as biocides, flame retardants, accelerators (for vulcanisation of rubbers), and colorants.

There are various pathways for plastic additives to reach the marine environment including industrial and municipal wastewater, atmospheric deposition, terrestrial runoff and riverine transport. In most instances, additives are not chemically bound to plastic polymers, and therefore can potentially move from within the polymers and leach out to the environment. Thus, they have been cited as a potential threat to ecosystems (Gallo et al., 2018; Franzellitti et al., 2019). Weathering can stimulate leaching of additives, with a higher rate suggested for saltwater environments (as exampled in Luo et al., 2019).

Polybrominated diphenyl ethers (PBDE), phthalates, nonylphenols (NP), BPA and antioxidants are the most common additives identified in the marine environment (Hermabessiere et al., 2017). Furthermore, there could be risk to biota exposed to these chemicals.

**Table 1.** Summary of plastic additives and macromolecules adapted from Hansen et al., 2013; Hahladakis et al., 2018; Gunaalan et al., 2020. Full table presented in Appendix (**Table 36**).

| **Group** | **Function** | **Examples** | **Comments** |
|---|---|---|---|
| *Functional additives* | | | |
| Antioxidant and UV stabilisers | Prevent degradation of polymers when exposed to UV irradiation. | Arylamines; Phenolics incl. BPA; Organophosphates. | Often used in food packaging incl. PP. |
| Anti-static agents | Minimize the build-up of static electricity or electric charge in plastic materials. | fatty acid esters, ethoxylated amines, ammonium compounds, alkyl sulfonates, and alkyl phosphates. | Most types are hydrophilic and can migrate to water. |
| Biocides | Provide protection from degradation by microbes, or as an antimicrobial surface. | Arsenic compounds, Organotin compounds, Triclosan. | Soft PVC and PUR. |
| Curing agents | Regulate the speed at which plastics harden and set. | Peroxides and other crosslinkers, catalysts, accelerators. | These additives allow manufactures to increase production efficiency. |
| Flame retardants | Flame retardants prevent or slow the further development of ignition. | Include three groups: organic, non-reactive, reactive; inorganics.<br><br>Paraffins, Brominated Flame Retardants, Phosphates, Boric acid. | Associated plastics include PE (LD-PE, HD-PE), PP, PS, ABS, PVC, PUR, unsaturated polyesters. |
| Foaming agents | Forms a propellant in the plastics unit, foaming plastics during processing. | Azodicarbonamide etc. | Depends on the density of the foam and the potential gas production of the agent. |
| Heat stabilisers | Prevent degradation of polymers when exposed to elevated temperatures. | Nonylphenol; Epoxy stabilisers Cadmium and lead compounds. | PVC and other PVC blends require heat stabilisers to maintain their function. |
| Lubricants, surfactants and slip agents | Reduce the surface coefficient of friction of a polymer. | Waxes, metallic, fatty acid amides. | Amount is dependent on chemical structure and polymer type. |
| Plasticisers | Improve flexibility, durability and stretchability of plastics. Improve impact resistance. | Paraffins, Phthalic esters, Adipates. Most common are BBP, DBP, DCHP, DEHP, DHA, HAD. | Most plasticizers are used in PVC. Other plastics include cellulose-based, PS, PET. |
| *Colorants* | | | |
| Water soluble colorants | Chemical compounds used to colour plastics. | Azocolorants. | Mostly used in PS, PMMA. |
| Pigments (mostly insoluble) and dyes (mostly soluble) | | Organic: Cobalt (II) diacetate Inorganic: Cadmium, Chromium and Lead compounds. | PE (LD-PE, HD-PE), PP, PS (HIPS), ABS, PVC, polyester (PET), PMMA, PC, polyamides (PA 6, PA 66), epoxy resins, unsaturated polyesters. |
| *Fillers and reinforcements* | Particles added to plastics to improve specific properties and reduce cost. | Calcium carbonate, Kaolin, magnesium hydroxide; Polymer foam beads etc. | Elastomers and plastics are the largest material group to use fillers. |
| *Monomers and oligomers* | Macromolecules that form plastic materials. | BPA, PS | PC, epoxy resins, unsaturated polyesters. |

ABS- Acrylonitrile butadiene styrene; BPA- bisphenol A; BBP- Benzyl butyl phthalate; DBP- Dibutyl phthalate; DCHP- Dicyclohexyl phthalate; DEHP- Di-(2-ethylhexyl) phthalate; DHA- di-heptyl adipate; HAD- heptyl adipate; HIPS- high impact polystyrene sheet ; PA- polyamide; PC- polycarbonate; PE-polyethylene (low and high density); PET- polyethylene terephthalate; PMMA- polyacrylamide; PP- polypropylene; PS- polystyrene; PUR- polyurethane; PVC- polyvinyl chloride; UV- ultra violet,

# 2 Methods

## 2.1 General

This study comprises of a tiered approach to quantifying sea-based sources of microplastic. The tailored approach consisted of first identifying whether there was any published literature or reports quantifying sources relevant to the Norwegian environment (Norway > Nordic Region > Europe). If this data was unavailable or not sufficient, existing datasets or data-inventories were assessed, followed by model predictions and personal communications. The approach followed the same four steps for each potential source to generate data required for estimation, validation and assessment of sea-based sources of microplastics (**Figure 2**).

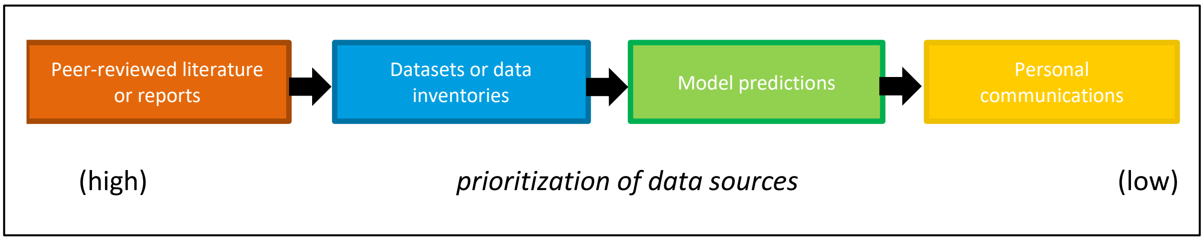


**Figure 2**. Tiered approach to data prioritization

## 2.2 Source categorisation

There have been numerous reports which have identified potential sources of microplastics to the marine environment (incl. Sundt et al., 2014; GESAMP, 2020). It must be noted that in most instances only estimates of potential microplastic releases are available and the source and associated values have not been confirmed. Thus, for the purpose of this report we refer to all sources as potential as they may or may not be verified and confirmed as a sea-based source to the Norwegian environment.

Potential sea-based sources of microplastics were grouped into sectors where activities were similar and had overlapping discharges into the marine environment (**Figure 3**). In this sense, paints and coatings were identified as a cross-sectional source, and a possible source across almost all sea-based activities. Therefore, nine predefined potential sources of microplastics were identified:

- Maritime coatings – application and maintenance, weathering
- Maritime traffic – shipping, cruises, ferries and other transport activities
- Ports, harbours, marinas and shipyards – maintenance, weathering, dredging
- Decommissioning
- Fisheries – wear and tear of active gear and lost, abandoned and otherwise discarded gear
- Aquaculture
- Petroleum activities including exploration, drilling and production
- Other offshore activities including windfarms
- Land-based industries with direct discharges to marine recipients

Potential sources are presented throughout the report following the order above.

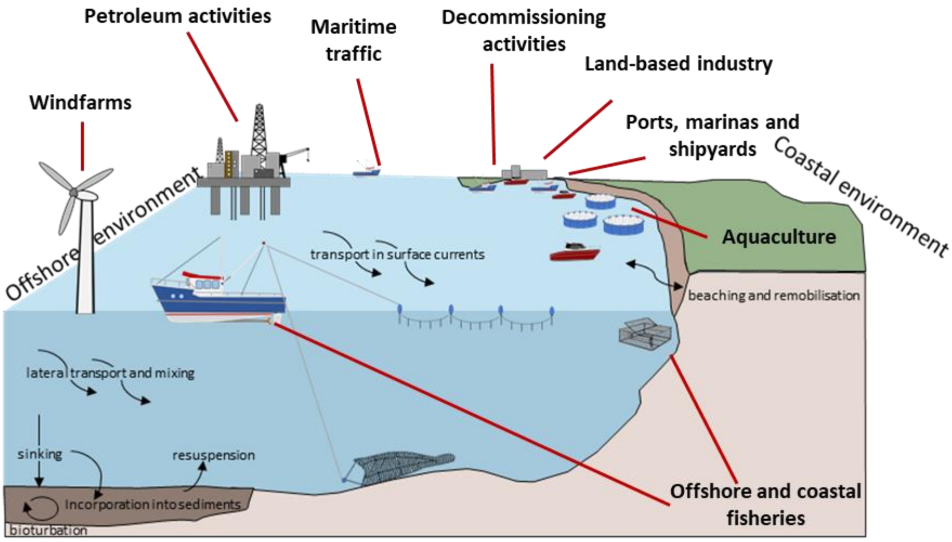


**Figure 3.** Conceptual diagram showing potential sources of microplastic into the marine environment on a national scale (modified from Lusher and Welden, 2020).

## 2.3 Data collection

There is currently no centralized location with data on plastic sources, or discharges of microplastics to the Norwegian environment. Several reports and peer-reviewed publications have been released in recent years which can be used to identify potential sources in Norway.

Firstly, a literature search of any published reports or peer-reviewed literature was conducted to cover the six years (2014 – October 2020) following the publication of the MEPEX report (Sundt et al., 2014) Data collection specifically focused on identifying information from Norway or the Nordic regions. Any information pertaining to emissions values for potential sources were recorded. An extensive search of databases and inventories was conducted when there was no data available in published literature. A list of databases accessed, the last date of access and the information obtained related to sources are included in **Table 2**. Next, a data search related to sources presented in model predictions was carried out. Lastly, if the search was inconclusive, direct communication was carried out with sectors and researchers working within the field. Where Norwegian data was unavailable, data from international sources was used to infer a situation for Norway.

**Table 2.** List of databases used for the assessment of potential sea-based sources of microplastics to Norwegian waters

| **Database** | **Relevant information for source** | **Data last accessed** |
|---|---|---|
| Norwegian Maritime Authority<br>https://www.sdir.no/ | Current vessel statistics – Size of Norwegian fleet | Oct 31st 2020 |
| Statistics Norway<br>https://www.ssb.no/ | Import and export of raw plastic material | Oct 21st 2020 |
| Norwegian Coastal Administration<br>https://beredskap.kystverket.no/ | Location of ports<br>Pellet spills related to MV Trans Carrier | Oct 31st 2020 |
| Norwegian pollutant releaser and transfer register<br>https://www norskeutslipp.no/ | Searched for:<br>- information on waste generated by decommissioning companies (offshore installations and ship-breaking) – no information available<br>- Information on land-based industries | Nov 30th 2020 |

## 2.4 Data handling

Each identified source (sector or activity) data has been assessed in order to identify the potential release of primary microplastics and the contribution to secondary microplastics in the marine environment. Each of the nine pre-defined potential source categories were described in terms of release (reason for discharge) and divided into the following sections:

(1) Description of the emission source including the cause and routes of transfer to the sea
(2) Period in life cycle that discharge occurs
(3) Quantity calculation of the source (including weight and number where possible)
(4) Microplastic polymer composition
(5) Microplastic size range
(6) Associated additives which are on the list of priority environmental toxins
(7) Description of the uncertainty related to calculations
(8) Missing data required to provide greater certainty in values
(9) Summaries of literature confirming the presence of microplastics related to source

Where there was more than one activity identified for each potential source, sub-categories were introduced. **Table 3** presents the source categories with subcategories and an overview of the data collected using the tiered approach for each potential source. Each source category or subcategory was addressed separately, and details can be found in the Section 7.

**Table 3.** Details on data sources for potential sea-based released of microplastics in Norway * These activities include the generation of paint.

| Category | Subcategory | Key peer-reviewed literature/reports | Datasets or data inventories |
|---|---|---|---|
| **Maritime coatings** | Application and maintenance* | 3, 4 | - |
| | Weathering* | 3, 10, 11 | - |
| **Maritime traffic** | Spillages of cargo (inc. pellets) | 2, 7, 8, 13 | Statistics Norway, Kystverket |
| | Operational discharges | 6, 8 | - |
| | Dumping | 6, 8 | - |
| | Shipwrecks | 8 | - |
| | Recreational boating | 8 | - |
| **Ports, marinas and shipyards** | Vessel maintenance | 3, 4, 7, 8 | - |
| | Weathering / wear and tear | 1, 3, 8 | - |
| | Dredging | 8 | - |
| **Decommissioning activities*** | - | None available | - |
| **Fisheries** | Wear from active gear | 1, 12 | - |
| | Loss of gear (incl. ALDGF) | 8 | - |
| **Aquaculture** | Operations, production, waste | 8, 9, 12, 14, 16 | - |
| | Loss of gear | None available | - |
| **Petroleum activities** | Oil and gas exploration, processing | 5 | - |
| **Other offshore activities** | Wind farms | None available | - |
| **Land-based industry** | - | 15 | Norsk Utslipp |

[1] Booth et al., 2017; [2] Cole and Sherrington, 2016 [3]; COWI, 2018 [4] COWI, 2019 [5]; EOSCA, 2016 [6]; Faulk-Andersson et al., 2019 [7]; Galafassi et al., 2019; [8] GESAMP, 2020; [9] Huntington, 2019; [10] IMO, 2019a; [11] IUCN, 2017; [12] Lusher et al., 2017; [13] Magnusson et al., 2016; [14] Sandra et al., 2020; [15] Sundt et al., 2014; [16] Vangelsten et al., 2019.

## 2.5 Assessment of data quality and uncertainties

An assessment of the data quality and uncertainty related to the different data sources was addressed using a Data Quality and Uncertainty Assessment Score (Hann et al., 2018), which was modified for the context of the Norwegian marine environment. Thus, allowing gaps in knowledge to be identified and new findings to be highlighted. Each potential sea-based source of microplastics was given two scores to reflect the certainty of the data from the source (Part A) as well as the data available from environmental studies (Part B).

For Part A, a matrix of four categories was developed: **Reliability** of data sources, **Completeness** of the available data, **Age** of the data and the **geographical** relevance to Norway. Each category was rated on a scale of 1 to 5, where 1 constitutes to verified and relevant data, and 5 is unknown and non-quantified estimates (**Table 4**). By applying a score to the matrix, the lowest score shows the best data quality. Each potential sea-based source could score a minimum of 4 (very high data quality) and a maximum of 20 (insufficient data quality). For Part B, the data pertaining to microplastics identified from environmental studies linked to a source is assessed based on a certainty level related to data quality and impact of the data – **high**, **medium, low.**

**Table 4.** Data Quality Matrix devised for potential sea-based sources of microplastics to Norway (Part A), modified from Hann et al., (2018).

| **Score** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

# 3 Potential sea-based sources of microplastics

Identifying and assigning sources of microplastics in the ocean is challenging. Microplastics are distributed widely in the ocean, emitted at different times and at different stages in their life cycle. The release of primary microplastics is by far the least complicated as sources can be identified, even if values related to emissions are still not obtainable. Most primary microplastics can be linked to production sites for plastics and paints which have discharges to the sea, or maintenance facilities in coastal areas. Whereas, secondary microplastics which are generated through breakdown could be derived from maintenance, decommissioning and wear and tear across various maritime sectors as well as the breakdown of large plastic items lost or discarded at sea.

Nine broad potential sea-based source categories are relevant to the Norwegian marine environment. These include maritime coatings (which have been defined as a cross-sectoral source), maritime traffic, ports marinas and shipyards, decommissioning activities, land-based industry (with discharged into the marine environment), fisheries, aquaculture, petroleum-related activities, and other offshore activities. These categories can be further refined into sub-categories (**Table 5**). An in-depth description of each potential sea-based source is presented in Section 7.

The quality of available data varied significantly between the nine broad categories. In general, it was found that that there is surprisingly little information on the quantities of microplastics released into ocean from coastal or other sea-based sources. In cases where values or estimates are available, very little advancement from earlier reports could be achieved (e.g., Sundt et al., 2014). Few of the source categories have some information available, but the certainty around the data for all source categories was classed as medium or low.

There are few field reports on the quantities of microplastics found in the Norwegian environment therefore validating emissions values is challenging. Furthermore, interpreting the data that does exist is even more complex. Small sample sizes do not provide enough data to work with estimates, and the particles identified often cannot be differentiated between sources.

The polymer type of microplastics will likely influence how far they disperse from their sources of input. Even though there are many polymer types with a range of marine applications, there is little empirical evidence to support this knowledge. Similarly, information on size of microplastics in the marine environment is spare, the data that is available is mostly related to studies of sediment, biota and water where particles were not assigned to specific sources (e.g., Bråte et al., 2018; Haave et al., 2019; Lusher et al., 2015). Further, the sizes reported are reliant on the analytical approaches applied.

Additives associated with microplastics require further investigation. Currently, observations of microplastics in the marine environment do not consider associated additives. The only information available is inferred from polymer type linked to source categories. The diversity of plastic polymers warrants targeted investigations into the use of plastics and their associated chemicals across all sectors identified.

For a thorough understanding of the sea-based sources of microplastics to the Norwegian marine environment, emissions estimates require knowledge of the material flow/plastic life cycle. Emissions estimates must be validated with targeted studies investigating the point sources and fluxes behind the release and dispersal of microplastics into the marine environment.

It is impossible to determine which sea-based source is the biggest contributor to microplastics in the Norwegian marine environment as there is little certainty behind the available data. The emissions values presented in this report are estimates rather than actual measurements. For example, if taken at face value, microplastics generated from fishing gear contribute the highest number of microplastics to the marine environment (1 000 – 10 000 tonnes a year) however this value is an estimate which is not support with any evidence of fishing gear degradation under Norwegian environmental conditions.

In order to compare the size of emissions from the different categories of sea-based sources, focus must be directed towards those instances where there is little to no empirical evidence available. This includes calculations of emissions based on actual reported discharge values and comparative environmental investigations.

The size of the maritime sector may also play a role in microplastic emissions. It will be necessary to investigate the size of the sectors and their relative emissions of microplastics in future research. In Norway, aquaculture, petroleum and fisheries are some of the biggest maritime sectors, whereas windfarms and decommissioning are smaller. Those smaller maritime sectors may only be contributing to a small proportion of the overall emissions to the marine environment, but no data currently exists to allow such a comparison to be made.

Lastly, methods of assessment employed must use similar and comparable methodology to allow evaluations across the different source categories.

**Table 5.** Summary of all potential sources of microplastics identified for the Norwegian environment. Each source is given and Data Quality and Uncertainty Assessment score (Part A) and a Certainty score (Part B). The certainty score specifically refers to the data of environmental levels of microplastics reported for Norway. Source data: Tier 1 – Peer-reviewed literature and reports, Tier 2 – Databases, Tier 3 – Modelling, Tier 4 – Personal communication. * denotes where only macroplastic data is available. No data both in Norway and internationally.

| Source | Source data | Part A<br>Assessment score | % discharge | Part B<br>Certainty score | Estimate of annual microplastic emissions (Tonnes, T) | Source |
|---|---|---|---|---|---|---|
| **Maritime Coatings** | | | | | | |
| Application and vessel maintenance | Tier 1 | 7 | ~ 30% | Medium | Recreational vessels – 103<br>Commercial vessels – 300 | [2, 5] |
| Weathering | Tier 1 | 9 | ~ 30% | Medium | Recreational vessels – 43 | [2] |
| **Maritime Traffic** | | | | | | |
| Cargo spills | Tier 1 | 19 | <0.0001% | Medium | *No data* | - |
| Pellets | Tier 1 | 7 | 0.5% | Medium | Import: 1 500, Export: 50 | *This report* |
| Operational discharge | Tier 1 | 12 | *unknown* | Low | *No data for Norway* | - |
| Dumping | Tier 1 | 6 | *unknown* | Low | *No data for Norway* | - |
| Shipwrecks | Tier 1 | 17 | *unknown* | Low | *No data for Norway* | - |
| Recreational boating | Tier 1 | 10 | *unknown* | Low | *No data for Norway* | - |
| **Ports, marinas, shipyards** | | | | | | |
| Vessel maintenance | Tier 1 | 7 | ~ 30% | Medium | Recreational vessels – 103 | [2] |
| Weathering/wear and tear | Tier 1 | 11 | *unknown* | Medium | Recreational vessels – 43 | [2] |
| Dredging | Tier 1 | 20 | *unknown* | Low | *No data for Norway* | - |
| **Decommissioning** | Tier 1, 2 | 20 | *unknown* | Low | *No data for Norway* | - |
| **Fisheries** | | | | | | |
| Active gear | Tier 1 | 10 | 0.5% | Low | 1 000 – 10 000 | [1, 5] |
| ALDFG | Tier 1 | 19 | *unknown* | Low | *No data for Norway* | - |
| **Aquaculture** | Tier 1, 3 | 9 | *unknown* | Medium | Feeding tubes: 0.1 – 100 t per site | [4, 7] |
| **Other offshore industry** | - | 20 | *unknown* | Low | *No data for Norway* | - |
| **Petroleum** | Tier 1 | 11 | *unknown* | Low | Norway and Iceland: 487<br>(102 excluding emulsifiers) | [3] |
| **Land-based industry** | Tier 1 | 12 | 0.1-0.2% | Medium | 10 – 50 tonnes of pellets directly into the ocean (no distinction between transport and production spills) | [6] |

[1] Booth et al., 2017; [2] COWI, 2019; [3] EOSCA, 2016; [4] Gomiero et al., 2020; [5] Sundt et al., 2014; [6] Sundt et al., 2021; [7] Vangelsten et al., 2019.

## 3.1 Source classification

The potential sources of microplastics to the Norwegian environment can be classified into ***Primary*** and ***Secondary*** sources (**Table 6**). Primary sources include the introduction of particles which are designed to be used in the size range of microplastics. Microplastics and paints may originate from land-based production sites which have discharges directly into the marine environment. The application of maritime coatings includes not only the paint particles yet to dry and harden, but also abrasive scrubbers used during vessel maintenance. Other shipping related discharges include small plastics spilled during shipping such as raw plastic pellets, microplastics used in commercial and cosmetic scrubbers which are discharged with grey water. Oil and gas activities also utilise plastic polymers as flocculants and surfactants.

Many of the potential sources contribute to secondary emissions: microplastics formed through the breakdown of plastic materials – either during use or at end of life – releasing microplastics to the marine environment. Any activity that utilises plastics can generate microplastics through weathering and wear and tear. Furthermore, any items lost or discharged to the marine environment can also break down.

**Table 6**. Classification of the sea-based sources of microplastics identified to potentially contribute to microplastics within the Norwegian marine environment. *denotes the inclusion of maritime coatings (paint), identified as a cross sectoral source.

| **Source category** | **Subcategory** | **Classification** | | **Identifiable release to the marine environment** |
|---|---|---|---|---|
| | | **Primary** | **Secondary** | |
| **Maritime coatings** | Application and maintenance* | ✓ | ✓ | Sanding and application of paints and coatings in shipyards |
| | Weathering | | ✓ | Vessels and other infrastructure* |
| **Maritime traffic** | Spillages of cargo | ✓ | ✓ | Loss during transport |
| | Operational discharges | ✓ | ✓ | Sewage |
| | Dumping | ✓ | ✓ | Waste thrown overboard |
| | Shipwrecks | | ✓ | Breakdown of plastic components and paint |
| | Recreational boating | | ✓ | Littering |
| **Ports, marinas and shipyards** | Vessel maintenance | ✓ | ✓ | Including air blasting, sanding and reapplication of maritime coatings |
| | Weathering / wear and tear | | ✓ | Weathering from boat hulls and other infrastructure* |
| | Dredging | ✓ | ✓ | Redistribution of settled particles |
| **Decommissioning activities*** | | | ✓ | Vessels and offshore platforms |
| **Fisheries** | Wear from active gear | | ✓ | Breakdown of in-use gear, loss of equipment (storm damage) and environmental weathering |
| | Loss of gear (incl. ALDGF) | | ✓ | |
| **Aquaculture** | Lost or abandoned equipment | | ✓ | Breakdown of in-use gear, loss of equipment (storm damage) and environmental weathering |
| | Production, operations, household, waste | | ✓ | |
| **Petroleum activities** | Oil and gas exploration, processing | ✓ | ✓ | Release of surfactants, weathering of structures |
| **Other offshore activities** | Wind farms | | ✓ | Weathering of installations |
| **Land-based industry** | Including plastic and paint production facilities | ✓ | | Spills during production, outflows to ocean |

## 3.2 Percentage discharge and emissions values

Few of the identified potential sea-based sources have reliable estimates of percentage discharge. Maritime coatings, including microplastics generated during application, maintenance and weathering are estimated to have ~30% discharge rates. These values have been generated from data related to paint application on recreational and commercial vessels (Sundt et al., 2014; COWI 2019). Other maritime structures, such as harbour walls, docks, offshore platforms etc. have not been considered. Far lower percentage discharges have been suggested for the generation of microplastics from active fishing gear and loss of plastic pellets during shipping (0.5% discharge). Other land-based industries were estimated at 0.4% and the loss of microplastics through cargo <0.001% discharge. All other potential source categories are unknown.

The estimated emissions give an indication of potential releases of microplastics from the identified source categories. The only available estimates of microplastics annually emitted to the sea are related to paint particles emitted from the application, maintenance and weathering of recreational vessels (43 – 88 tonnes), the loss of pre-production resin pellets transport at sea – during import and export (1 550 tonnes), the fragmentation of active fishing gear (1 000 – 10 000 tonnes), the generation of microplastics from aquaculture feeding tubes (0.1 – 100 tonnes), and the emissions of microplastics from petroleum activities (data available for the UK and Norway combined). All other potential source categories are unknown. The data presented here suggested that the fragmentation of active fishing gear possibly contributes the most microplastics to the marine environment. However, as the knowledge of the breakdown of plastics in the marine environment is scare, there is low certainty around these estimates, and they must be used with caution. Further research is needed to understand the processes of weathering and degradation under different environmental conditions.

## 3.3 Polymer types and sizes

The polymers linked to potential sources of microplastics are varied (**Table 7**). For many of the sources, such as those where plastics are derived from the breakdown of larger plastics in the marine environment it was not possible to identify specific polymers. As there have been so few studies investigating microplastics in the Norwegian environment, information on size is sparse, the data that is available is mostly related to studies of sediment, biota and water where particles were not assigned to specific sources (e.g., Bråte et al., 2018; Haave et al., 2019; Lusher et al., 2015) and the sizes reported are reliant on the analytical approaches applied. The most certain size of microplastics from sea-based sources are the spills of pre-production pellets, which are generally reported to be between 1 and 5 mm in length (although powders can be smaller). Data on microplastics released from aquaculture production processes suggests that particles can be from 2.1 to 80 µm in size (Gomiero et al., 2020).

Data on fragmented items – possibly related to the weathering of boats and other maritime structures or released from paint production facilities – have been reported in the size range of 11 – 300 µm (Haave et al., 2019; Noren and Naustvoll, 2011). Paint particles released during maintenance could be as small as 50 nm (Koponen et al., 2009). There is currently no data on the size of microplastics related to dredging, decommissioning, wear and tear of active fishing gear, petroleum activities and other offshore activities. Similarly, there is no data on the breakdown of macroplastics into microplastics following dumping, cargo spills, recreational boating or lost and discarded fishing and aquaculture equipment.

**Table 7**. Polymers identified to be linked to the potential source categories of sea-based sources of microplastics within the Norwegian marine environment. *denotes the link to maritime coatings and paints.

| Category | Subcategory | Acrylics* | Epoxy resin* | EVA | PA | PC | PE | PET | PP | PUR* | PS | PVC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Maritime coatings** | Application and maintenance* | ✓ | | | | | | | | ✓ | | |
| | Weathering* | ✓ | | | | | | | | ✓ | | |
| **Maritime traffic** | Spillages of cargo, including plastic pellets | ✓ | | | | | ✓ | | ✓ | | ✓ | |
| | Operational discharges | | | | | | ✓ | | ✓ | | | |
| | Dumping | ✓ | | | ✓ | | ✓ | ✓ | ✓ | ✓ | | |
| | Shipwrecks | | | | | | | | | | | |
| | Recreational boating | | | | | | | | | | | |
| **Ports, marinas and shipyards** | Vessel maintenance | | | | | | | | | | | |
| | Weathering / wear and tear | ✓ | | | ✓ | ✓ | ✓ | | | ✓ | | ✓ |
| | Dredging | ✓ | | ✓ | | | | | | | | |
| **Decommissioning*** | | | | | | | | | | | | |
| **Fisheries** | Wear from active gear | | | | ✓ | | ✓ | | ✓ | | ✓ | ✓ |
| | Loss of gear (incl. ALDGF) | | | | ✓ | | ✓ | | ✓ | | ✓ | ✓ |
| **Aquaculture** | Lost or abandoned equipment | | | | ✓ | | ✓ | ✓ | ✓ | | | |
| | Production, operations, household, waste | | ✓ | | | | | | | | | |
| **Petroleum activities** | Oil and gas exploration, processing | | | | | | | | | | | |
| **Other offshore activities** | Wind farms | | | | | | | | | | | |
| **Land-based industry** | Including plastic and paint production facilities | ✓ | | | | | ✓ | | ✓ | | ✓ | |

## 3.4 Associated additives

It was challenging to identify associated additives for most of the potential sea-based sources of microplastics. Much of the reason behind this is related to the diversity in the plastic polymers used across the potential source categories. Maritime coasting and paints which are relevant across the source categories of ***application and maintenance*** and ***weathering of maritime coatings***, both for **<u>vessel traffic</u>** and **<u>ports and marinas</u>** have the most available information (**Table 8**).

**Table 8**. Additives identified to be linked to the potential source categories of sea-based sources of microplastics within the Norwegian marine environment. Priority list and candidate list refer to the Norwegian priority environmental toxins. *denotes the link to maritime coatings and paints. Modified from Hansen et al., 2013.

| Category | | Additive name | Associated plastics | Comments |
|---|---|---|---|---|
| Functional additives | Antioxidant/UV stabilsers | Acrylamide | PMMA | EDC |
| | | Benzotriazole | Epoxy resins, PUR | PBT |
| | | Cadmium compounds | PVC and other coloured plastics | EDC |
| | | Carbamates | PUR | EDC |
| | | Lead compounds | PVC, HDPE, PP, LDPE | EDC |
| | | Phenols (BPA, BPS, BPF) | PE, PP, PVC, epoxy resins | EDC |
| | Antistatic | Ammonium compounds | Textile fibres | Candidate list |
| | | Fatty acids (amides, esters, stearates, waxes) | PA, PVC, PP, PE | - |
| | | PFOA | PTFE, PVDF, PUD | Priority list |
| | Biocide | Parabens inc. BPA | Rubber products inc. SBR | EDC |
| | | Phenols | PE, PP, PVC, epoxy resins | EDC |
| | | Triclosan | PE, PP, PVC, PES, PA | EDC |
| | | TBT * | PUR, PVC | EDC |
| | | Zinc pyrithione* | Textiles and paints | EDC |
| | | Zineb* | Paints | EDC |
| | | Ziran* | Paints | EDC |
| | Curing agents | Anilines | Epoxy resins | EDC |
| | | BPS | PMMA, PUR, epoxy resins | Candidate list |
| | Flame retardants | Boric acid | Non-woven polymers, PS | EDC |
| | | Brominated flame retardants | PS (EPS, XPS, HIPS), PE, PP, PUR, ABS, resins | EDC |
| | | Chlorinated paraffins | PE, PP, PVC, PUR, modified cellulose | PBT, vPvT |
| | | Phosphates (e.g., TCEP) | PUR, PVC, PA, PC, PMMA, PES | EDC |
| | Foaming agent | Fluorinated gases | PTFE | - |
| | | Chloromethane (Methyl chloride) | PS, PE, PP, PUR, phenol resins, acetyl cellulose foams | EDC |
| | | Diazene-1,2-dicarboxamide | PVC, PE, epoxy resins | Toxic |
| | Heat stabiliser | Cadmium compounds | PVC and other coloured plastics | EDC |
| | | Lead compounds | PVC, HDPE, PP, LDPE | EDC |
| | | Phenols (inc. NP) | Epoxy, PVC, PP, PS | EDC |
| | Lubricants etc. | PFOA | PTFE, PVDF, PUD | Priority list |
| | Plasticizers | Adipates | PVC | EDC |
| | | Acetyl tributyl citrate | PVC | - |
| | | Chlorinated paraffins | PE, PP, PVC, PUR, modified cellulose | PBT, vPvT |
| | | Phthalates/phthalate esters | PVC, PVA, PMMA, PET, PES, ABS, PS, PUR, acrylic, modified cellulose | EDC |
| | | Phosphates | PVC, PUR, PES, PA, PC, PMMA | EDC |
| | | PAHs | ABS, PP | Carcinogenic |
| Colorants | Pigments | Cadmium compounds | PVC and other coloured plastics | EDC |
| | | Chromium compounds | PE | Priority list |
| | | Cobalt (II) dictate | PET | EDC |
| | | Lead compounds | PVC, HDPE, PP, LDPE | EDC |
| Fillers and Reinforcements | | Polymer foam beads | - | - |
| Monomers and oligomers | | BPA | PC, epoxy resins, PUR | EDC |
| | | Octyl phenols | PVC, PP, PS | EDC |
| | | Styrene | PS | Carcinogenic |

ABS – acrylonitrile butadiene styrene; BPA – bisphenol A; BPF – bisphenol F; BPS – bisphenol S; EDC – endocrine disrupting chemical; EPS – expanded polystyrene; HDPE – high density polyethylene; HIPS – high impact polystyrene sheet; LDPE – low density polyethylene; NP – nonylphenol; PA – polyamide; PBT – persistent, bioaccumulative and toxic; PE – polyethylene; PES – polyester; PET – polyethylene terephthalate; PFOA – perfluorooctanoic acid; PMMA – polyacrylamide; PP – polypropylene; PS – polystyrene; PTFE – polytetrafluoroethylene; PUD – polyurethane dispersion; PUR – polyurethane; PVA – polyvinyl alcohol; PVC – polyvinyl chloride; PVDF – polyvinylidene fluoride; TCEP – tris(2-chloroethyl) phosphate; SBR – styrene-butadiene rubber; TBT – tributyl tin; XPS – extruded polystyrene.

## 3.5 Data quality

The quality of the available data on sources of microplastics to the Norwegian marine environment varies between the identified potential sources (**Figure 4**). When the Data Quality and Assessment score was applied across the 18 fine-scale categories, only 6 were given scores reflecting a high-level of available information. This include all maritime coatings (application and maintenance, weathering), two within maritime traffic (pre-production plastic cargo, dumping), only vessel maintenance within the broad category of ports and harbours, and aquaculture. Most of the identified source categories had very little data meaning they were marked as low or poor information available this included cargo spills, shipwrecks, dredging, decommissioning, breakdown of ALDFG and offshore industries.

Looking into the finer details and the contributing factors towards these scores, it is clear that much more information is needed to obtain quality data across all scoring fields (**Table 9**). On average the **reliability** of the data scored worse, followed by **completeness** of the data. **Temporal** and **geographical** scored highest. These scores reflect the balance of the available data. On one hand there has been many reports recently published within Norway and the Nordic region on microplastic sources. On the other hand, the reports are mostly presenting estimates, which are not validated with environmental observations.

Specifically,

- **Reliability** was rated based on the data sources that were accessed, eight of the source categories were awarded the score of 5, meaning that the source was yet to be estimated, or a non-qualified estimate existed. Three of the source categories had a qualified estimate, seven of the sources had non-verified data based on estimates. None of the data was verified based on assumptions or environmental measurements.
- **Completeness** was rated based on the data sources addressing all potential point sources within a category with enough level of detail. Three of the categories were awarded 5 as they are currently unquantified sources. Twelve of the sources had few data available but they were unsubstantial, and three of the sources contained some data. None of the categories were identified to have representative data on the quantities of microplastics originating from the identified sources.
- **Temporally,** much of the available data was relatively recent. Eleven of the source categories have data (albeit non-qualified estimates) generated from the last 3 years. Still, six sources have no data available.
    - **Geographically** much of the data was relevant to Norwegian (9 sources), Nordic (2 sources) or European conditions (2 sources). Five of the source categories vastly different, or unknown, geographical conditions.

**Table 9.** Data Quality and Assessment score values obtained for the 9 potential source categories

| | Minimum score | Maximum score | Average |
|---|---|---|---|
| **Reliability** | 2 | 5 | 4.0 |
| **Completeness** | 1 | 5 | 3.7 |
| **Temporal** | 1 | 5 | 2.4 |
| **Geographical** | 1 | 5 | 2.4 |

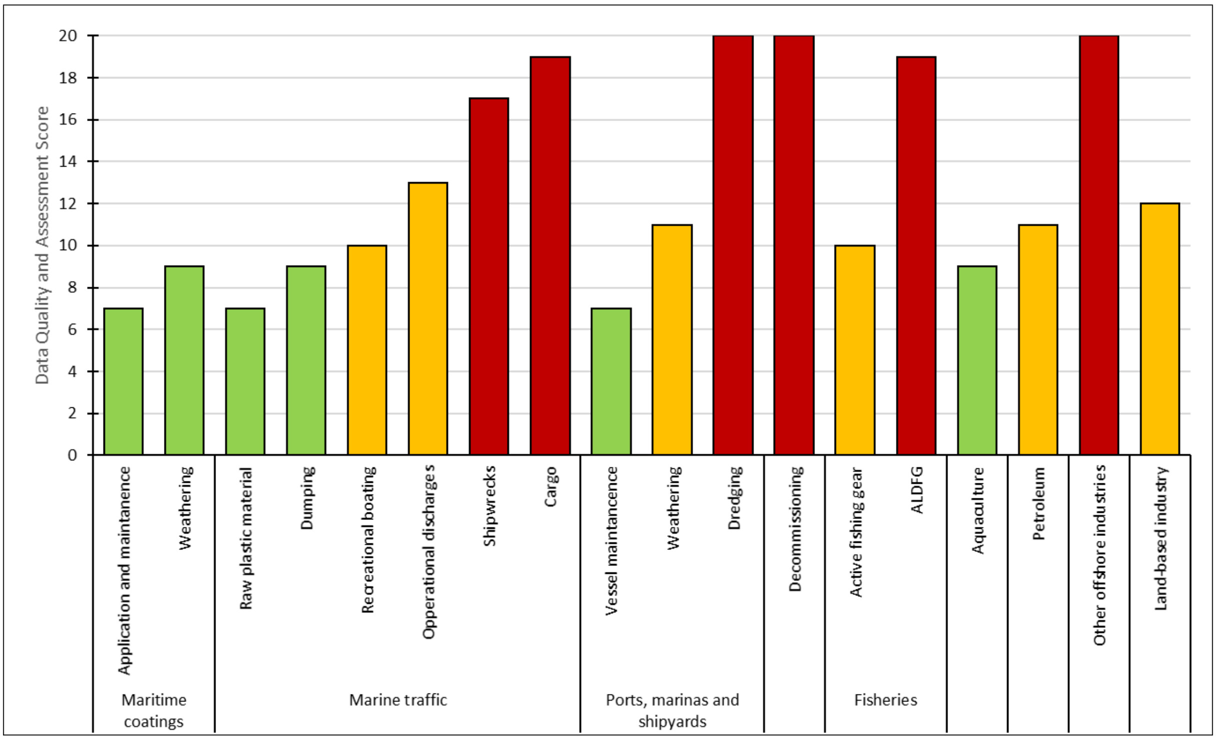


**Figure 4.** Data Quality and Assessment score applied to each of the identified potential sources of microplastics to the Norwegian marine environment. For full break down of scores please refer to Section 356.

The next phase of the assessment on the certainty of the values related to discharges. Each potential source category was assessed on knowledge of the source and validation through environmental studies. Importantly, none of the identified source categories were classified as **HIGH CERTAINTY**, meaning that none of the available information is enough to accurately quantify a source. Eight categories scored **MEDIUM CERTAINTY** and 10 scored **LOW CERTAINTY**. This highlights the need to conduct specific investigations into the identified source categories to understand their contribution as a source to microplastics in the marine environment.

# 4 Discussion – Microplastics from sea-based sources

## 4.1 Source importance

In order to identify which source is the most important – or the largest contributor to the microplastic loads in the Norwegian marine environment – we must first conduct studies into the actual values of emissions. Estimates give an indication, but they cannot be relied on for data assessments.

Currently, the only available data on microplastics entering the Norwegian marine environment are related to estimates of paint particles emitted from the application, maintenance and weathering of recreational vessels (COWI, 2019), the loss of pre-production resin pellets transport at sea – during import and export (which are only a small proportion of the materials shipped every year), the fragmentation of active fishing gear (Booth et al., 2017), the generation of microplastics from aquaculture feeding tubes (only one of the possible sources of microplastics within the aquaculture supply chain) (Gomiero et al., 2020; Vangelsten et al., 2019), and the emissions of microplastics from petroleum (data available is combined for UK and Norway; EOSCA, 2016).

Referring to only these data, the breakdown of active fishing gear appears to be the biggest source of microplastics to the Norwegian marine environment (**Table 10**). However, investigations must be performed to validate these estimates as a low certainty score has been applied. Importantly, none of the values presented in this report were classified as having a high certainty. The breakdown of items in the environment, including fishing gear (active and ALDFG) and the weathering of structures have the least certain numbers. This is most likely related to the lack of good scientific understanding surrounding the processes of weathering and degradation.

**Table 10.** Estimated microplastic release from potential sources of microplastics.

| | Tonnes | | Certainty score | Reason for certainty score |
|---|---|---|---|---|
| | Minimum | Maximum | | |
| Breakdown of active fishing gear | 1 000 | 10 000 | Low | Estimates of degradation |
| Import of raw plastic material | - | 1 500 | Medium | Calculated from import values and % discharge estimates |
| Maritime coatings – commercial vessels | - | 300 | Medium | Calculated from emissions estimates and known usage of paints |
| Petroleum activities | 102 | 487 | Low | Calculated from emissions estimates |
| Feeding tubes | 0.1 | 100 | Medium | Calculated from targeted investigation (observed values) |
| Maritime coatings – recreational vessels | 43 | 88 | Medium | Calculated from emissions estimates and known usage of paints |
| Export of raw plastic material | - | 50 | Medium | Calculated from export values and % discharge estimates |

It is not possible to discern which of the potential sea-based sources identified in this report is the biggest contributor to marine microplastics. Neither is it possible to discern whether sea or land-based sources are the biggest contributors to microplastics in the environment. A parallel assessment has been conducted on land-based source (Sundt et al., 2021). Both reports used different approaches to assessing the available data and it is not easy to draw comparisons. The current report focused on an environmental approach, assessing data quality and trying to validate estimates, whereas the parallel report calculated estimates based on production values.

The lack of environmental data, both on emissions values and monitoring of specific recipient matrixes (water, sediment, biota – inshore and offshore) are the biggest challenge to understanding the complex dynamics of microplastic emissions to the Norwegian environment. The first step in understanding the scale of potential sources is to identify them, as has been done in this report. The next step is to study each source and understand how they contribute to the overall microplastics loads in the marine environment. To do so, targeted assessments must be performed utilising rigorous methodological approaches that can be compared between potential source categories. Once data is collected, values came be compared between potential sources, allowing for a better understanding of the largest contributing source, or sector, to environmental concentrations of microplastics. Assessments may need to be conducted on local, regional and national scales to reflect the distribution of different sectors. A structured approach to understanding microplastics sources and emissions will allow regulators to take a targeted approach to mitigation and/or remediation actions (**Figure 5**).

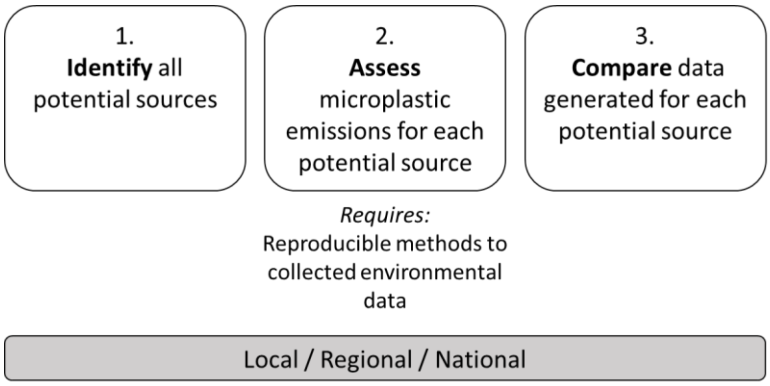


**Figure 5.** Suggested approach to addressing sources of microplastics to the Norwegian environment

## 4.2 Comparison to European data

The European assessment of microplastic sources covered both land- and sea-based sources (Hann et al., 2018). Overall, it found that land-based sources contributed the most to microplastic emissions with automotive tyres, road markings, raw plastic material (terrestrial, aquatic and marine sources) and effluents from washing processes equating to the largest sources. Pre-production plastics, fishing gear and marine paints were identified as sea-based sources (**Table 11**). When comparing the estimates generated for Europe (Hann et al., 2018) to those from the present report, fishing gear was identified as the highest contributor (when upper and mid-point estimates are used). However, when the lower estimates are included the shipping of raw plastic material (Norway) and marine paints (EU) appear to be bigger contributors (**Figure 6**).

There are several limitations when comparing between the European data and the Norwegian data on sea-based sources. The current report identified many more potential sea-based sources, limiting comparisons as there is a lack of comparable data. Furthermore, the European study addressed the emission pathways including terrestrial, aquatic and marine systems. The report highlighted that only a proportion of the land microplastics emissions will reach the aquatic environment. This may be is disproportionate as marine sources were not considered to the same extent as land-based due to limited data (Hann et al., 2018)

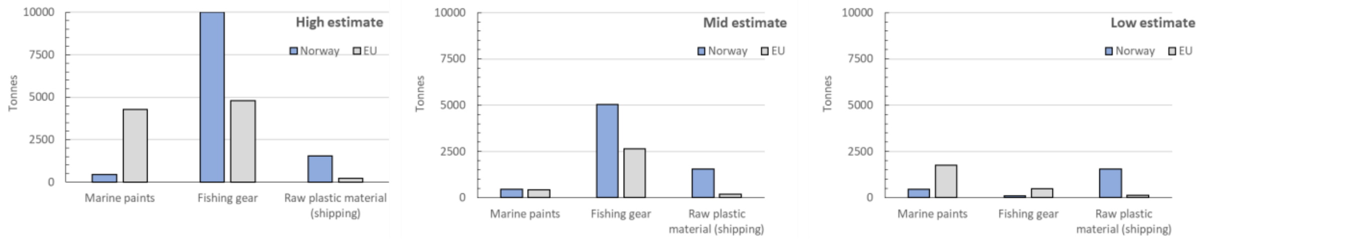


**Figure 6.** Comparison of microplastic source emissions between European (Hann et al., 2018) and Norwegian data (this report)

**Table 11.** Complication of Norwegian and European data related to the potential sea-based sources of microplastics identified for this report.

| | | Norway | | Europe | |
|---|---|---|---|---|---|
| **Category** | **Subcategory** | **% discharge** | **Quantity Emitted to the sea annually** | **% discharge** | **Quantity Emitted to the sea annually** |
| **Maritime coatings** | Application and maintenance* | ~30% | Recreational vessels: 103<br>Commercial vessels: 300 | 7 – 35% | 1 752 – 4 284<br>Midpoint:1 194 |
| | Weathering* | ~30% | Recreational vessels: 43 | | |
| **Maritime traffic** | Spillages of cargo | <0.0001% | *No data for Norway* | 0.001 – 0.002% | 191 – 225 |
| | Plastic pellets | 0.5% | 1 500 tonnes import<br>50 tonnes export | 0.001 – 0.002% | 141 – 225<br>Midpoint: 183 |
| | Operational discharges | *unknown* | *No data for Norway* | No data | No data |
| | Dumping | *unknown* | No quantitative estimate available | No data | No data |
| | Shipwrecks | *unknown* | *No data for Norway* | No data | No data |
| | Recreational boating | *unknown* | *No data for Norway* | No data | 400 |
| **Ports, marinas and shipyards** | Vessel maintenance | ~30% | Recreational vessels: 103 | No data | 1 752 – 4 284<br>Midpoint:1194 |
| | Weathering / wear and tear | ~30% | Recreational vessels: 43 | | |
| | Dredging | *unknown* | *No data for Norway* | No data | No data |
| **Decommissioning*** | | *unknown* | *No data for Norway* | No data | No data |
| **Fisheries** | Wear from active gear | 0.5% | 1 000 – 10 000 tonnes | 0.4 – 1% | 478 – 4 780<br>Midpoint: 2629 |
| | Loss of gear (incl. ALDGF) | *unknown* | *No data for Norway* | | |
| **Aquaculture** | Lost or abandoned equipment | No data | No data | No data | No data |
| | Production, operations, household, waste | *unknown* | Feeding tubes: 0.1 – 100 tonnes per site per year | No data | No data |
| **Petroleum activities** | Oil and gas exploration, processing | No data | No data | No data | 487 (102) |
| **Other offshore activities** | Wind farms | No data | No data | No data | No data |
| **Land-based industry** | Production facilities | 0.2 – 0.4% | 10 – 50 direct to the sea | No data | No data |

## 4.3 Knowledge gaps

There are still many knowledge gaps surrounding microplastic sources to the Norwegian marine environment. Our understanding of sea-based sources is particularly hampered by the complex nature of source categories, emissions values and the subsequent dispersal of microplastics into the marine system. Particles can be dispersed and move far from source locations, indicating the necessity to focus on emission locations. Unfortunately, many of the sea-based sources do not have fixed discharge points. For example, maritime vessels are continuously moving between shipping routes and port facilities compared to fixtured structures such as offshore installations with identifiable discharge points. This situation is made further complex when trying to assess the generation of secondary microplastics from in-use plastics, or those that have been lost or discarded within the marine environment as the breakdown mechanisms are far from being realised. Secondary microplastics may provide an indication of the stage of the product lifecycle at which they were emitted to the ocean although the presence does not provide an understanding of which manufactured plastic products the microplastics are derived from. Regions where some industry sectors are a prominent feature may be a starting point to monitoring microplastic sources and emissions, for example aquaculture locations and land-based industry with discharges into the coastal marine environment. Similarly, the redistribution of microplastics from one location to another should be addressed. As an example, dredging is responsible for the movement of sediment within the marine environment. It is undeniable that dredging will facilitate microplastics redistribution and transport. However, it may be hard to distinguish between local sources of input compared to transported materials. Specific studies should monitor the consequences of dredging operations.

### 4.3.1 Maritime coatings

More information is required on commercial vessels. As well as investigations into the emissions of paints during cleaning and maintenance in coastal areas. Information could be gathered in combination with long term monitoring of contaminated sediments (e.g., Russ et al., 2019).

### 4.3.2 Maritime traffic

Mapping the release and distribution of microplastics related to shipping is challenging as vessels are in motion and crossing between national and international waters. Maritime paints have been identified as a source and estimates built on production values are available, however more information should be gathered to support these estimates. Currently, much of the information focuses on recreational vessels within Norway. All vessels categories including commercial ships should be taken into consideration. Further, the calculations should be validated with environmental measurements. Very little information is available on the operational discharges and dumping from all vessel types operating in Norwegian waters. These discharges should be characterised further. Similarly, volumes of shipping losses along with the dispersal of materials from points of emissions should be investigated further including investigations into the breakdown of plastic items under Norwegian environmental conditions. The plastic components of shipwrecks should be investigated for the release of microplastics and breakdown over time.

### 4.3.3 Ports, marinas, shipyards

Application, cleaning and other maintenance activities will release microplastics to the marine environment from vessels and other maritime structures. Available information is connecting mostly to recreational vessels and all maritime infrastructure should be assessed. Furthermore, spillages of maritime coastings should also be considered. Volumes of dredged material should be investigated for the likely hood of redistribution of plastics from contaminated areas to other marine locations.

### 4.3.4 Decommissioning

As there is currently no available data on decommissioning facilities in Norway the potential for sites along the Norwegian coasts to release plastics and microplastics should be assessed.

### 4.3.5 Fisheries

The release of microplastics from fisheries is associated with the use of active gear (weathering) as well as lost and discarded gear (breakdown). There are many different plastics utilised within the fisheries sector and future studies need to assess difference in gear types between small- and large-scale fisheries operations – and the generation of microplastics both during use and once lost at sea under Norwegian environmental conditions. For example, the environmental conditions in the Arctic fishing grounds of the Barents Sea are very different from the offshore fisheries in the southern Norwegian sea. It will be necessary to distinguish between active and lost gear. This will rely on detailed reporting of lost fisheries items to better establish estimates of gear lost to the environment and how much, and over what duration, they will break down if not retrieved.

### 4.3.6 Aquaculture

Very little information surrounding microplastics released from aquaculture operations is available. The information which is available focuses on specific activities across few companies. Moving forward, all aspects of the supply chain should be addressed in similar and comparable ways. Including the release of microplastics form in-use gear as well as items lost to the environment. Furthermore, the scale of aquaculture as a source should be addressed.

### 4.3.7 Petroleum and other offshore activities

Petroleum and other offshore operations require further investigation. Assessments from the petroleum sector are hindered as the working definitions of microplastics do not necessarily encompass the polymers used within this industry. Without clear guidance on what should be reported it is impossible for companies within this sector to assess potential microplastic emissions. It will be imperative to consider the definitions used for “microplastics” and broader definitions will need to be adopted to incorporate other polymers. Further still, assessments could be made which utilised environmental monitoring programs for contaminants, where discharges from a platform are monitored (e.g., Brooks et al., 2011).

Other offshore industries including windfarms should be further investigated.

### 4.3.8 Land-based industries and activities

When information on land-based industries is available, it does not distinguish between land and sea-based discharges. Moving forward, all industries with known or potential discharges directly into the coastal marine environment should be assessed for emissions. Once a baseline of emission from a source is established, they can be monitored for changes in emissions volumes or mitigation and remediation efforts can be put in place.

### 4.3.9 Assessment methods must be comparable

One of the underlying limitations in the assessment of microplastics is the adoption of comparable and replicable approaches to sampling, processing and data interpretation. Many methods are employed within Norway, as well as internationally and it is imperative that guidelines for monitoring microplastics are adopted given the high profile of microplastics as a contaminant source. Indeed, methods are continuously developing, such as focusing on smaller microplastics (<20 µm). Methods which are adopted must utilised the best available methods that have been rigorously tested and validated. When new methods are adopted and undergo similar validation procedures, a level of data comparison will be maintained. OSPAR, ICES, AMAP, GESAMP and other regional bodies are all in the process of identifying the methods and/or guidelines for member states. Countries should begin to adopt currently recommended procedures and start expert consultation surrounding what, and importantly, why they are going to monitor. This process has already begun in Norway. Comparable monitoring tools will allow comparisons between data generated for land- and sea-based sources of microplastics, as well as between industries and sectors with different scales of microplastic emissions. Comparable methods also facilitate better interpretation of the pathways and transports of microplastics within the environment. Thus, allowing for baselines to be established, fluxes in emissions to be monitored and allow for hazards and risks assessments associated with observed emission concentrations. Furthermore, monitoring tools adopted internationally will allow comparisons within and between countries, as well as regional seas.

# 5 Conclusion

There is surprisingly little information on the quantities of microplastics released into ocean from coastal or other sea-based sources. Future research must focus on obtaining comparable empirical data across all potential source categories. This includes calculations of emissions based on actual reported discharge values and comparative environmental investigations.

The information presented in this report is in agreement with the GESAMP Working Group 43 looking into Sea-Based Sources of Marine Litter. They stated in their second interim report (GESAMP, 2020) that it was not possible to estimate the total contribution of sea-based activities and industries to the global burden of marine litter because very little quantification of marine litter exists in the scientific, peer-reviewed and grey literature.

Moving forward, investigations into the potential sea-based sources identified throughout this report should be conducted utilising validated and comparable methods. This will allow a better understanding of the contributions of different sectors and industries to the Norwegian sea-based microplastics emissions and support mitigation and remediation efforts in the future.

# Appendix

# 6 Summary of assessment scores

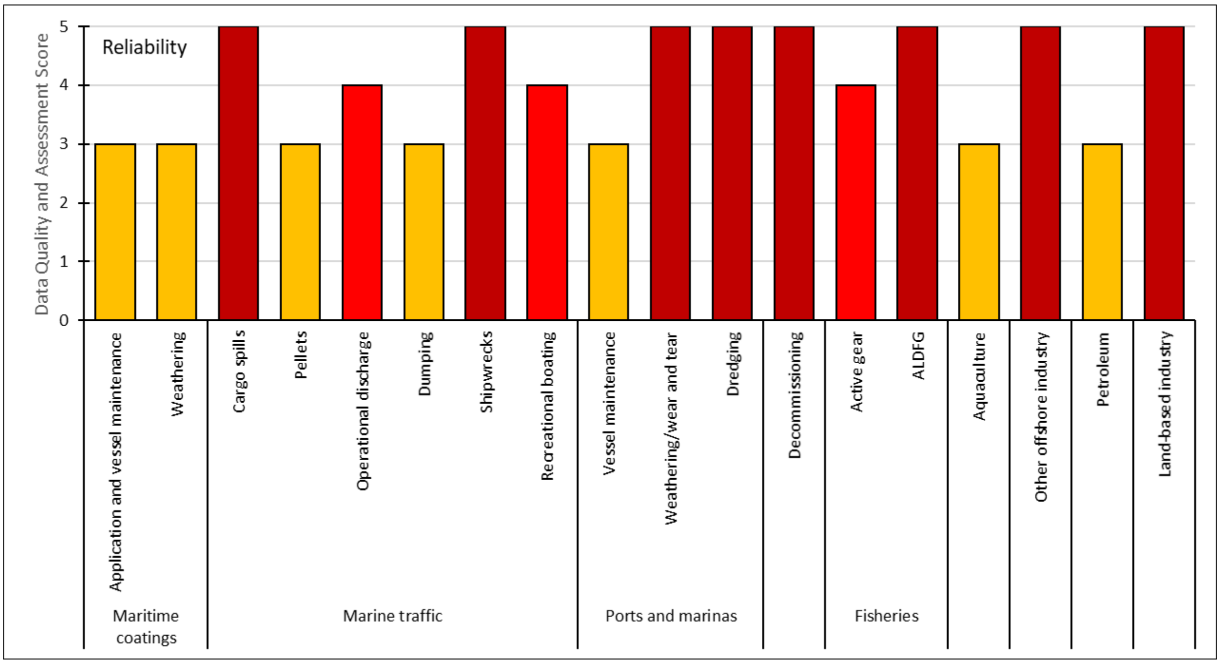


**Figure 7.** Data Quality and Uncertainty Assessment Score related to reliability of data on sea-based sources of microplastics. Each category could be awarded a score of 1 to 5, where data was: verified by measurements (1), verified by data partially based on assumptions (2), non-verified data based on estimates (3), qualified estimate by an expert (4), non-qualified estimates (5).

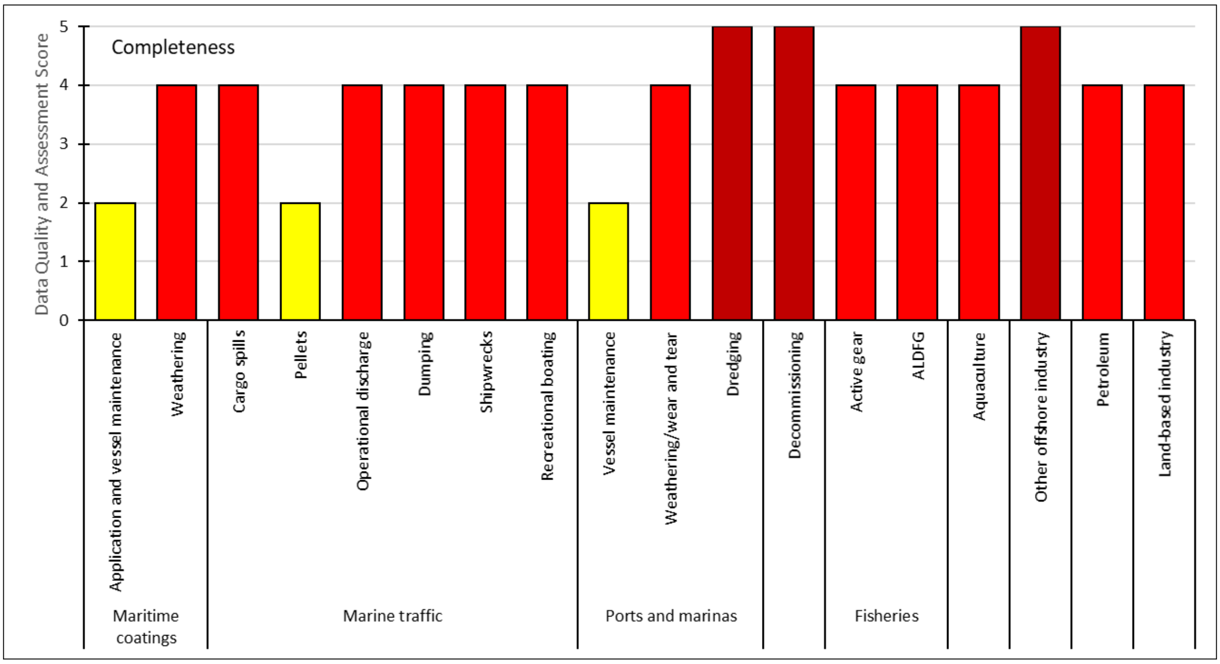


**Figure 8.** Data Quality and Uncertainty Assessment Score related to completeness of data on sea-based sources of microplastics. Each category could be awarded a score of 1 to 5, where data was: representative (1), had some representativeness (2), limited representativeness (3), little representativeness (4), non-existent or unknown (5).

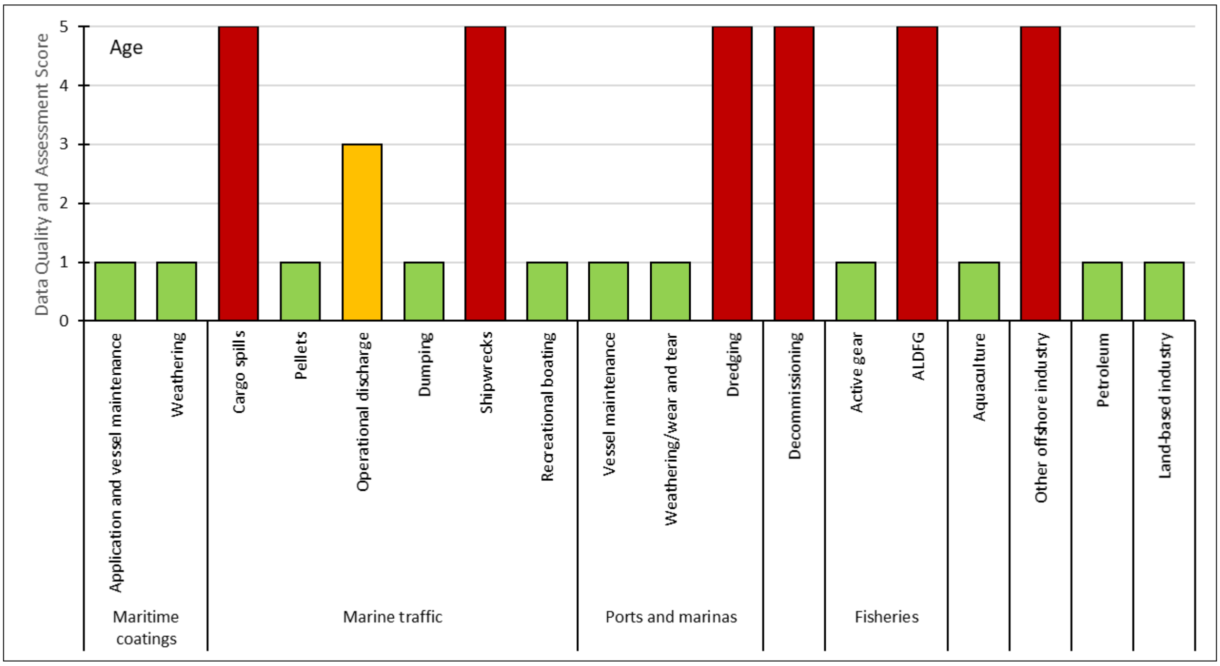


**Figure 9.** Data Quality and Uncertainty Assessment Score related to the age of data on sea-based sources of microplastics. Each category could be awarded a score of 1 to 5, where data was: <3 years old (1), <6 years old (2), <10 years old (3), <15 years old (4), non-existent or unknown (5).

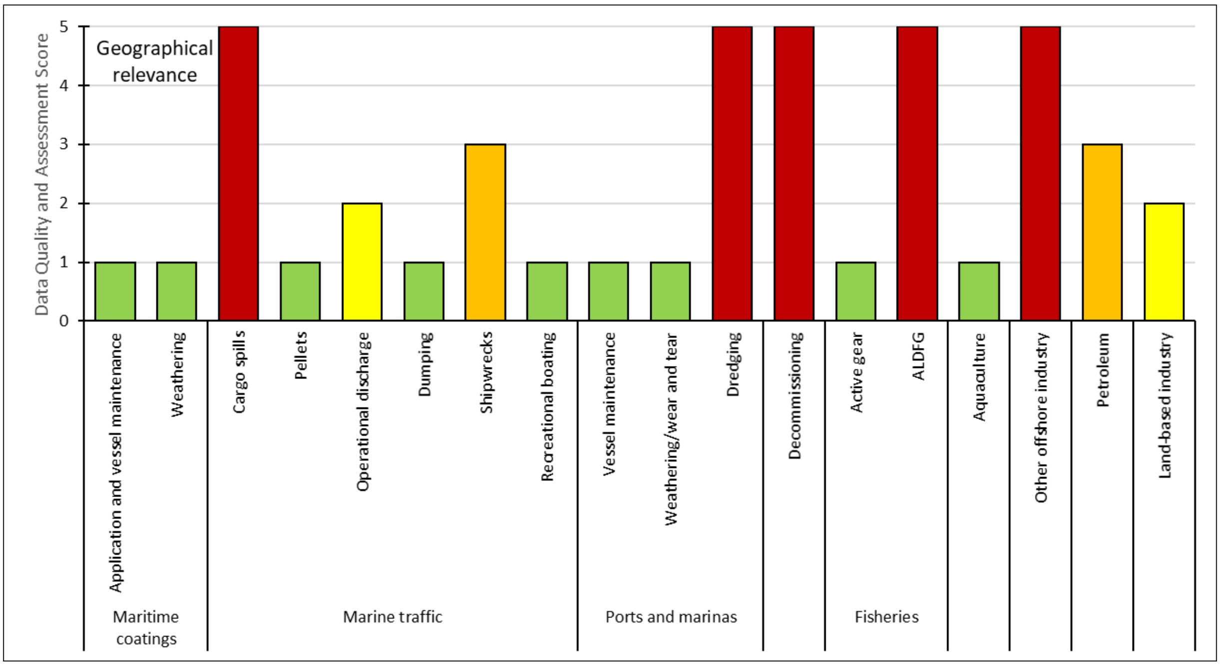


**Figure 10.** Data Quality and Uncertainty Assessment Score related to the geographical relevance of data on sea-based sources of microplastics. Each category could be awarded a score of 1 to 5, where data was: Norwegian (1), Nordic (2), European (3), had similar geographical conditions (4), vastly different or unknown (5).

# 7 Assessment of potential sea-based sources of microplastics

## 7.1 Maritime coatings including paints

Maritime coatings are designed to protect coastal and marine structures, including vessels. These coatings are mostly used to mitigate biofouling (from sessile organisms), to smooth surfaces, and to protect from the corrosive elements of the marine environment (incl. seawater, weathering and wave action). Marine structures and vessels made of metal are covered in epoxy-based paint with an overcoat to increase resistance to UV light. Coatings include solid coatings, anti-corrosive paints and antifouling paints – many of which contain various types of plastic.

Microplastics can be added to maritime coatings for many reasons past those of anticorrosion and foulants, these include surface effects, colour enhancers, improve their application, increase hardness and resistance to scratches (Lassen et al., 2015). Specifically, paints contain different types of plastic polymers including polyurethane (PUR), epoxy coatings and copolymers (OECD, 2009a). The self-polishing activity of anti-foulant paints makes them loose microparticles continuously to maintain contact with water (Galafasi et al., 2019). Maritime coatings not only contain a variety of plastic polymers, they also contain plastic additives. Many of these additives are controlled due to the detrimental impact they may have on the marine environment.

- **Antifouling coatings** are used to inhibit and mitigate the settlement and growth of marine species (Daffron et al., 2011). The antifouling paints containing tributyl tin (TBT) were the preferred choice, but many negative effects were observed which led to the International Maritime Organization (IMO) banning the application of TBT containing coatings globally from January 2003 and required its absence as an active coating on all vessels after 1 January 2008 (IMO, 2001). Other antifouling coatings have been developed which include biocidal coatings which are listed as Controlled Depletion Polymers (CDPs), Self-Polishing Copolymers (SPCs) and Hybrid SPCs (Demierl, 2018).

- **Anti-corrosion protection** for metals are designed to prevent degradation related to exposure in the marine environment. This includes corrosion related to moisture, salt spray, oxidation and other environmental contaminates. There are many different products on the market which also contain plastic polymers. Epoxy polymers with carbon soot nanoparticles (derived from polyolefin plastics) are one such example (Korde et al., 2020).

Regardless of the composition of maritime coatings, their high density means that when fragments are released, they sink rapidly and are not likely to move far from source locations. Spills of paint residues or flaking from painted objects in coastal areas will be deposited in the sediments and will therefore potentially pose a threat to the marine environment (Johnsen and Engøy, 2000). One environment that may receive an influx of paint particles are the coastal harbours and shipyards. In many instances, the high levels of TBTs and polychlorinated biphenyl (PCB) contaminants have been linked to the application of maritime paints including antifoulant coatings (e.g., Jartun et al., 2009; Jartun and Pettersen, 2010; Paetzel et al., 2003; Russ and Green, 2002).

On a global scale, the International Union for Conservation of Nature (ICUN) estimated marine coatings contribute to 3.7% of global release of microplastics (Boucher and Friot, 2017). A report for the

European Commission published in 2018 highlighted that there was no spatial scale data to disaggregate the total marine paint sales by application (Hann et al., 2018), but they did find that ECHA had produced estimates of the amounts of anti-fouling paints sold in the EU (25 000 tonnes, ECHA 2013) along with an estimate from OECD that commercial and recreational vessels account for 95% of this demand (OECD, 2005). Based on these data, Hann et al., (2018) estimated that a total of 1 194 tonnes of marine paint are emitted annually.

Roughly 8% of maritime paints from Europe are consumed in Norway. There have been two different estimations related to release of paint particles: Sundt et al., (2014) and COWI (2019).

Below, the application of maritime coatings and weathering is addressed. Although it must be noted that everywhere a boat is in transit there is a potential for weathering to occur, and thus a release of coatings into the surrounding waters, sinking to the sediment. Similarly, shipwrecks may also be a source of secondary microplastics as they succumb to the marine environment (shipwrecks are discussed as their own entity in Section 7.2.4)

The production of paint subsequent and spills of product directly into the marine environment - is included under land-based industries (Section 7.9).

### 7.1.1 Application and maintenance

*Description:* Martine coatings are applied to all parts of a vessel for protection. This includes the hull, external decks and superstructures, as well as on-deck equipment. Routine maintenance is required for up-keep. In most instances, this can be yearly cleaning of boat hulls and the reapplication of coatings following abrasive scrubbing. Sundt et al., (2014) reported that modern epoxy based maritime paints emit particles fulfilling the microplastic definitions when spilled during application or removed during abrasive blasting. Paint flakes may enter the marine environment from maritime applications (maintenance, application, abrasive scrubbing, decommissioning) and can transfer from waterside facilities including boat yards and dry docks.

*Industry or sector linked to release:* Shipyards, maintenance facilities, ports, dry docks, marinas

*Period in life cycle that discharge occurs:* use, maintenance

*Quantity calculation of source:* A report from 2000 suggested that during the spray painting of a vessel a significant fraction (up to 30%) is released to the environment (OECD, 1973 in Johnsen and Engøy, 2000) and the greater part of it is drained to the harbour basin.

The Norwegian consumption of maritime paint was suggested to be in the region of 8 000 tonnes - 75% for professional use on large vessels, 25% recreational craft (Sundt et al., 2014). When the OECD emission factor (11%) and polymer binder content (25%) are considered the estimated annual emission were in the region of 165 tonnes. Sundt et al., (2014) estimated that the application of paints and maintenance and construction would probably be greater than the % estimates made by the OECD (2009b). They assumed under a worse-case scenario that paint application to commercial and recreational vessels could account for an annual microplastics emissions of 330 and 400 tonnes respectively, with another 270 tonnes generated through maintenance and construction.

Following an in-depth assessment of maritime paints on Norwegian recreational vessels (< 15 m in length), it was estimated that approximately 260 000 litres of antifouling paint was used each year, averaging of 0.84 litres per vessel per year (COWI, 2018). The routine maintenance and cleaning of recreational vessels may release 43 tonnes of microplastics into the Norwegian marine environment each year, equating to approximately 0.135 kg of microplastics per year per boat (COWI, 2019).

Additionally, a single Norwegian recreational boat uses approximately 1.1 kg antifouling paint each year. When considering that antifouling paint may contain 25% polymer binders that may become microplastics (OECD, 2009a), COWI estimated that each leisure boat may release 0.18 kg if microplastics during maintenance and cleaning. Scaling this up to the 321 000 leisure boats requiring a fixed dock in Norway, this equates to approximately 88 tonnes of microplastics per year (COWI, 2019).

A summary of the available data is presented in **Table 12**. It is not possible to update these values for maritime structures or commercial vessels as there have been no dedicated studies to microplastics generation during application and maintenance.

**Table 12**. Estimated annual emissions (tonnes) of maritime coatings during application and maintenance of vessels.

| | **European** (Hann et al., 2018) | **Norway** (Sundt et al., 2014) | **Norway** (COWI, 2019) |
|---|---|---|---|
| Generation and wear of marine paints | 1 194 | | Recreational: 43 |
| Total emissions to water "un-cured" paints during application | 1 993 – 4 525 | Commercial: 330<br>Recreational: 400 | |
| Application, maintenance, construction | | 270 | Recreational: 88 |

*<u>Microplastic polymer composition:</u>* Polyurethane acrylic (PUR/Acrylic) resins are a diverse group of polymer blends with different specific gravities (Osswald et al., 2006). They are commonly used for paints and boat varnish. Other antifouling coatings have been developed which include biocidal coatings which are listed as CDPs, SPCs and Hybrid SPCs (Demierl, 2018).

*<u>Microplastic size range:</u>* There have been no studies specifically addressing the release of particles vessel maintenance, however, Haave et al. (2019) identified PUR particles in the size range 11 – 300 µm in sediments from Bergen Fjord. These sources of these paint particles could be related to maritime activities within the fjords or coastal industries.

*<u>Associated additives:</u>* Maritime coatings are a complex mixture of polymers and ancillary compounds. Such ancillary compounds can include anti-corrosion pigments, UV resistance, and antifoulant compounds. Many of the non-polymeric compounds can be considered environmentally hazardous, including TBT, chlorothalonil, chromium trioxide, copper pyrithione, copper thiocyanate, dichlofluanid, diuron, folpet, Irgarol 1051, DCOIT (Sea-Nine 211), TCMS pyridine, TCMTB (Busan), Tralopyril, Zinc pyrithione, Zineb, Ziram (Thomas and Brooks, 2010; Tornero and Hanke 2016).

*<u>Description of the uncertainty:</u>* ***Data source: Tier 1 – publications and reports***
The currently available data is not enough to provide a solid estimation of the release of microplastics through application and vessel maintenance. The only data available is derived from estimates and has not been verified with a study to monitor loss of particles during application and maintenance (**Table 13**). **Therefore, the data quality assessment score applied to application and maintenance is: 7**

**Table 13.** Data Quality and Assessment Score for the application and maintenance of maritime coatings

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* The estimated emissions of maritime applications of paint are related to applications primarily on recreational vessels or estimated related to paint sale and consumption in the EU. Therefore, the following information is required:

- Data related to commercial vessels undergoing application and maintenance in Norwegian waters
- Precise emissions from cleaning (generation of paint particles) and application (spillage)

Summaries of literature confirming the presence of microplastics related to source: Although there are no studies in Norway directly related to vessel maintenance, one study from the UK identified that antifouling paint particles (500 µm – 2 mm) in estuarine sediments in the vicinity of areas of vessel maintenance and vessel abandonment (Muller-Karanassos et al., 2019). Values for vessel maintenance areas had a maximal concentration of 430 particles $L^{-1}$ (0.2 g $L^{-1}$). Similar particles were also found in the guts of the deposit feeding ragworm, *Hediste diversicolor* (Muller-Karanassos et al., 2019).

In Norway, paint particles were the most numerous microplastic identified in sediments collected from Byfjorden outside of Bergen. They accounted for 37.3% of the total particles identified. Highest proportion of PUR/acrylic particles were found close to Kvernavika (Haave et al. 2019).

Plastic fragments as components of paint have been identified in a number of regional investigations. For example, epoxy resins (EVA) and polyacrylics were detected in biota from the Oslofjord (Bråte et al., 2018a, 2020; Bour et al., 2018), and polymethyl acrylamide (PMMA) fragments were identified in amphipods from Svalbard (Iannilli et al., 2019). Unfortunately, it was not possible to identify where these particles came from, only that EVA is used in boat paints and PMMA is used in coatings for antifouling in marine environment, coating for waterproofing and corrosion protection.

Paints have also been observed in sediment samples during investigations of small boat harbours (NGI, 2011). Early studies have focused on contaminants related to paints, for example, TBTs, PCBs and heavy metals including copper (Cu) and zinc (Zn) were identified in harbour sediments that were likely related to the antifouling boat paints and decommissioning in Bergen, Drammen, Trondheim and Sørfjord (Jartun et al., 2009; Jartun and Pettersen, 2010; Paetzel et al., 2003; Russ and Green, 2002).

### 7.1.2 Weathering

*Description:* Exposure to environmental conditions and wear and tear, can lead to the release of paint fragments, and thus microplastics. The hulls of vessels are subject to constant wear and tear, caused by contact with harbour walls, vessels and other installations. These activities cause paint to deteriorate and flake (**Figure 11**), releasing particles directly to the surrounding environment. The high density of paints means that they sink rapidly and are likely to not be moved far from source locations. Therefore, paints can be found in high concentrations in ports and harbours, but also anywhere a vessel has been in transit paints may be found in sediments.

**Figure 11. A recreational vessel with a weathered hull. Photo: Amy Lusher**

*Identification of industry or sector linked to release:* Shipping, vessel activities, harbour activities.

*Period in life cycle that discharge occurs*: use

*Quantity calculation of source:* It has been estimated that approximately 15 tonnes of the microplastics originating from maritime paint will be released into the ocean whilst recreational vessels (<15 m) are at sea, equating to 0.43 kg of microplastics per boat per year (COWI, 2019). Additionally, a single Norwegian leisure boat uses approximately 1.1 kg antifouling paint each year. When considering that antifouling paint may contain 25% polymer binders that may become microplastics (OECD, 2009a), COWI estimated that each leisure boat may release 0.09 kg of microplastics whilst the boat is in the water for the season (COWI, 2019). There is currently no data available for commercial vessels.

No field studies concerning degradation rates of maritime coatings are available.

*Microplastic polymer composition:* PUR and other acrylic resins are commonly used for paints and boat varnish. Other antifouling coatings have been developed which include biocidal coatings which are listed as CDPs, SPCs and Hybrid SPCs (Demierl, 2018).

*Microplastic size range:* There have been no studies specifically addressing the release of marine coatings through weathering. The weathering of paint is mainly caused by UV irradiation, the formation of rust on metallic surfaces and maintenance. The sizes of fragments could vary, although an assessment of dust produced through wearing and sanding suggests particles can be between 50 nm to 3 µm (Koponen et al., 2009). One study had to exclude paint particles (Epoxy resins. 10 – 300 µm) from the analysis of water samples as they matched the hull of the sample vessel which is an example of wear and tear (Noren and Naustvoll, 2011). Haave et al. (2019) identified PUR particles in the size range 11 – 300 µm in sediments from Bergen Fjord. These sources of these paint particles could be related to application or other maritime activities within the fjords or coastal industries.

*Associated additives:* Vessel paints are a complex mixture of polymers and ancillary compounds. Such ancillary compounds can include anti-corrosion pigments, UV resistance, and antifoulant compounds. Many of the non-polymeric compounds can be considered environmentally hazardous, including TBT, chlorothalonil, chromium trioxide, copper pyrithione, copper thiocyanate, dichlofluanid, diuron, folpet, Irgarol 1051, DCOIT (Sea-Nine 211), TCMS pyridine, TCMTB (Busan), Tralopyril, Zinc pyrithione, Zineb, Ziram (Thomas and Brooks, 2010; Tornero and Hanke 2016).

*<u>Description of the uncertainty:</u>* ***Data source: Tier 1 – publications and reports***
The currently available data is not enough to estimate the release of microplastics through the weathering of maritime coatings. The information that exists is focused on recreational vessels (**Table 14**). **Therefore, the data quality assessment score applied to wreathing of maritime coatings is: 9**

**Table 14.** Data Quality and Assessment Score for weathering of maritime coatings.

| Score | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*<u>Missing data required to provide greater certainty in values:</u>* The estimated emissions of microplastics through weathering are related to recreational vessels and the processes of weathering and poorly described. Therefore, the following information is required:

- Description of weathering and release of particles through weathering under Nordic conditions
- Data related to commercial vessels operating in Norwegian waters, including those that are transitory and have home docks.

<u>Summaries of literature confirming the presence of microplastics related to source:</u> IMO (2019a) reports 6 – 7% of marine coasting are lost directing to the environment during the lifetime of a vessel. 1% of which is estimated to be related to weathering (Magnusson et al., 2016). Paint fragments and varnishes (EVA) have been identified in deep sea sediments as well as sea ice (Peekan et al., 2018 and references therein). Paint particles have also been identified in polychaetes from Norwegian marine environment, it was not possible to identify the source, given the locality from the shore, it is possible that they are the result of vessel weathering (Arp et al., 2018, Iannilli et al., 2019, Bour et al., 2019).

## 7.2 Maritime traffic

Shipping is used as a major transport route of products and services for Norway, including import and export of products and materials. The sector covers a range of vessels from local and international ferries, cruise lines, cargo ships, tankers, recreational craft, and military vessels (**Figure 12**). The discharges from maritime traffic are similar when compared by vessel type and therefore discussed by discharge type, with reference to a specific vessel type where relevant. The three categories of sea-based sources of microplastics related to maritime traffic are: Spillages, Operational discharges, Dumping and Recreational boating. Weathering of vessel paint is already covered under Section 7.1.2.


**Figure 12.** Maritime traffic activities that could contributes to release of microplastics to the marine environment. Primary microplastics are depicted as green, secondary microplastics as blue.

Many of the environmental issues originating from ships in the sea are addressed under MARPOL 73/78 (The International Convention for Prevention of Pollution from Ships) and restricted use, discharge and handing of different products from ships are regulated by IMO convention (**Table 15**). Maritime traffic may be responsible for the inputs of micro and macroplastic items to the marine environment, the reason for discharge may be accidently through poor handling, unfavourable weather conditions or deliberate dumping. For example, merchant ships and cruise liners may lose waste items including packaging materials, boxes and plastic sheets. Cargo vessels may lose plastic items including raw plastic material, pre-production pellets. Further, microplastics may be released during grey water management and transported through ballast waters (Section 7.2.2), derived from the routine cleaning of ships hulls (Section 7.3.1) and wear and tear of marine coatings (Section 7.3.2).

Globally, approximately 53 000 merchant ships are registered to the IMO. They are composed of general cargo (32%), bulk carriers (22%), tankers (30%) and passenger ships (10%) (GESMAP 2020). In terms of the Norwegian fleet there are:

- Approximately, 6 000 Norwegian fishing vessels including (5 500 less than 15 m in length, 2 250 between 15 – 25 m in length and 240 > 256 m) (Nordic Council of Ministers, 2020).
- Approximately 321 000 pleasure vessels 7 – 15 m with fixed docks (COWI, 2019)
- It was not possible to identify the number of passenger and mobile offshore unites registered on the Norwegian international Ship Register.

In general, it is hard to identify the relative contributions of plastics from maritime traffic. Shipping is expected to generate 25% and 4 – 10% of litter found in The Baltic Sea and North Sea (Strand et al., 2015; GESAMP 2020). It is not possible to find corresponding information for Norway. The IMO recently began international discussions and IMO's 73rd Marine Environment Protection Committee (MEPC) adopted the agenda "***Development of an Action Plan to Address Marine Plastic Litter from Ships***" in October 2018 (Jo, 2020).

Unfortunately, understanding the different types and categories of plastic litter derived from shipping and spillages requires knowledge on where, how and when plastic litter items are being lost or disposed of into the marine environment (GESAMP, 2020). Most non-operational waste has no exclusive source.

Evaluating the composition of shipping related litter is challenging because very few studies have focused on the question of the amount of plastic that comprised total shipping related litter items (GESAMP, 2020). This said, it is still not possible to infer how much microplastic is generated from these items. Distinguishing between the source, such as spillages and dumping will remain a challenge. One source that is less challenging to identify than others – due to their characteristic shape – are loss of preproduction pellets during transportation (Section 7.2.1.1).

**Table 15**. IMO conventions controlling the discharge, handling and usage of hazardous products on ships, with specific reference to plastics and microplastics. Modified from Lindgren et al., 2016.

| IMO Convention | Regulates | Adopted | Entered into force |
|---|---|---|---|
| MARPOL 73/78 | Pollution from ships | 1973/78 | 1983 |
| *Annex IV* | *Sewage* | *1973* | *2003* |
| *Annex V* | *Garbage* | *1973* | *1988* |
| International convention on the control of harmful anti-fouling systems on ships | Antifouling paints | 2001 | 2008 |
| Hong Kong International Convention for the safe and Environmentally Sound Recycling of Ships | Recycling of shipwrecks | 2009 | n.a. |
| Nairobi International Convention on the removal of wrecks | Removal of wrecks | 2007 | 2015 |

### 7.2.1 Spillages of cargo

*Description:* A wide range of products containing plastic compounds are shipped in containers, as well as the raw plastic material to make other products. Unfortunately, extreme weather conditions at open sea can be dangerous for cargo vessels. Waves in the open ocean can cause ships to heave, pitch and roll and compromise the stability of a vessel's load. Further, improperly loaded containers can hinder stability. Thus, stacked container ships are subject to extreme motions and at risk of falling into the sea (Galafassi et al., 2019).

Any loss of shipping contents is a direct release of items into the marine environment. This source of release can account for microplastics (e.g., pre-production resin pellets, Section 7.2.1.1) but also large plastic items (e.g., user-products). The larger products will subsequently breakdown if they remain in the environmental for extended periods of time. Water currents and winds will facilitate the dispersal of buoyant items, whereas heavier items will sink.

In a recent review, Galafassi and colleagues (2019) stated that the estimation of containers lost at sea each year is controversial, varying dramatically depending on who provided the data and suggested that the most comprehensive survey are the data from the World Shipping Council (WSC). In its annual reports, WSC estimated that an average of 568 containers were lost at sea every year (2008 – 2016), however this value increased to 1 582 when catastrophic losses are included.[3] The shipment of synthetic polymers, rubbers and plastic pellets are classed as hazardous for the marine environment (HME) under MARPOL Annex V.

*Identification of industries or sectors linked to release:* Shipping and cargo

*Discharge from product lifecycle*: Transport and shipping

*Quantity calculation given of source:* The loss of shipping containers is hard to quantify as they are usually not included as a source of marine litter because companies can be reluctant to release data about the weight and the nature of the goods lost (Galafassi et al., 2019). There is also no centralised database containing such values.

In a recent update, the WSC[4] reported that the average annual container loss were 1 382 individual containers (2008 – 2019), this value is less than 1/1000 of 1% of the total containers shipped per year (~226 million). In their review, Galafassi and colleagues suggested that an average shipping container – with a weight of 26.5 tonnes and containing a plastic content 50 – 70%, would result in the release of approximately 300 – 10 500 tonnes of plastic litter directly to the sea.

**There is currently no data available to estimate the amount of plastics and microplastics entering the Norwegian environment from losses during shipping.**

Furthermore, it is challenging to distinguish between losses in the Norwegian environment compared to losses in the open waters outside of Norwegian territories as spills can be transported with current over long distances. Furthermore, the breakdown of large plastic items is not quantified as the complex nature of fragmentation of different products has not been fully explored.

*Microplastic polymer composition:* One can assume that the list of plastic polymers derived from shipping spills would be as diverse and complex, therefore an exhaustive list is not included here.

*Microplastic size range:* There have been no studies specifically addressing the size of items spilled into the Norwegian marine environment.

*Associated additives:* One can assume that the list of plastic associated additives from weathering would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
There is currently no available data on shipping spills in the Norwegian environment (**Table 16**).
Some information exists on spills related to plastic pellets which is addressed in the next section.
**Therefore, the data quality assessment score applied to cargo spill is: 19.**

[3] https://www.worldshipping.org/industry-issues/safety/Containers_Lost_at_Sea_-_2017_Update_FINAL_July_10.pdf
[4] https://www.worldshipping.org/Containers_Lost_at_Sea_-_2020_Update_FINAL_.pdf

**Table 16.** Data Quality and Assessment Score for cargo spills.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* The release of plastics during shipping spillages cannot be presently described. Therefore, the following information is required:

- Volumes of shipping losses in the Norwegian marine environment
- Quantities and fragmentation potential of lost items

Summaries of literature confirming the presence of microplastics related to source: Section 7.2.1.1

### 7.2.1.1 Plastic pellets

*Description:*

Plastic pellets[5] are the raw material used to generate plastic products. They can be produced in a variety of shapes and sizes (**Figure 13**), including cylinders, spheres, beads and powders (OSPAR, 2018; Karlsson et al., 2018). They are most typically 2 – 5 mm in diameter and 1 kg pellets typically equates to 50 000 pellets (Cole and Sherrington 2016). Loss of plastic pellets can occur during production and transportation and during processing (Karlsson et al., 2018). Plastic pellets have been found along the Norwegian coast and it is assumed these have been released from local production facilities or spillage at sea. The levels on Norwegian shorelines are elevated around plastic production sites or factories processing these raw materials (Sundt et al. 2014; Kommedal 2018).

**Figure 13. Pellets found on shorelines of the Oslofjord. Photo: Inger Lise Nerland Bråte**

According to Norsk Industri[6], there are around 200 Norwegian companies currently working with plastics. Since many of these industries are located near the coast, and spills are likely to end up in the marine environment (Sundt et al., 2014; Kommedal, 2018). Importantly, there is willingness from industry to be a part of the solution. Operation Clean Sweep[7] is a voluntary program developed by Plastic Industry Association (PLASTICS) and The American Chemistry Council (ACC), and PlasticsEurope[8] is responsible for this programme in Norway. The purpose of the program is to change the attitude in the industry in relation to spills, with a goal of a zero-emission rate of plastic raw materials (Kommedal,

[5] Also known as **nurdles** or **mermaid's tears**
[6] https://www.norskindustri.no/bransjer/plastindustri/
[7] http://www.opcleansweep.eu/
[8] https://www.plasticseurope.org/en

2018). It is not possible with today's technology to fully clean up a pellet loss. Pellets losses can be numerous, and their density (such as PE and PP) facilitate them to float on water currents to different coastal regions where they can wash up on shorelines.

_Identification of industries or sectors linked to release:_ Shipping, production

_Discharge from product lifecycle_: Production, transportation, processing

_Quantity calculation of source:_ OCED gave an emission factor of 0.5% (5 grams released for every kg handled) for the transport and loss of solid powders as a worse-case scenario.

According to SSB[9], around 300 000 tonnes of raw plastic material were imported to Norway in 2019 (Appendix, **Table 37**). PE, PS, acrylic and PP was the most common polymers imported based on weight. Using the 0.5% emission rate, this could equate to a possible loss of 1 500 tonnes (1 500 000 kg) of raw plastic materials in 2019 alone. Similarly, around 10 000 tonnes of raw plastic material were exported from Norway in 2019 (Appendix, **Table 38**). By applying the same 0.5% emissions rate, this could equate to a possible loss of 50 tonnes of raw plastic materials in 2019.

A similar study in the UK estimated that 1.6 – 16 billion pellets were lost annually during shipping equating to 32 – 320 tonnes (Cole and Sharrington, 2016).

_Microplastic polymer composition:_ One can assume that the list of plastic polymers derived from shipping spills would be as diverse and complex, therefore an exhaustive list is not included here. Some of the most common plastics imported and exported in Norway are PE, PP, PS and acrylic.

_Microplastic size range:_ There have been no studies specifically addressing the size of items spilled into the Norwegian marine environment. Sizes generally 1 – 5 mm (Sundt et al., 2014), but raw plastic material is also available in powder form (<1 mm).

_Associated additives:_ One can assume that the list of plastic associated additives from spills of pellets would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

_Description of the uncertainty:_ ***Data source: Tier 1 – publications and reports, Tier 2 – databases, Tier 4 – personal communication***

Some information exists on spills related to plastic pellets (**Table 17**)., but these are mainly newspaper reports. Those pellets lost in the open ocean may not be necessarily linked to releases in Norwegian waters, and oceanic transport should be considered as a transport mechanism for items spilled internationally into Norwegian waters. **Therefore, the data quality assessment score applied to pellet spills is: 7**

[9] https://www.ssb.no/statbank/table/08801/chartViewLine/.

**Table 17.** Data Quality and Assessment Score for pellet loss.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* The loss of pellets and raw plastic materials during shipping has been well defined but we lack information in terms of quantities lost to the Norwegian environment. Therefore, the following information is required:

- Volumes of shipping losses in the Norwegian marine environment

Summaries of literature confirming the presence of microplastics related to source: It is clear from field studies on the Norway coast that spills are occurring, whether historical or recent.

A Norwegian master thesis investigating loss of raw plastic materials conducted interviews which identified that damage to wrapping material can lead to losses (Kommedal, 2018). There was also an example of PVC powder being lost, which would be much harder to identify in the environment as raw plastic materials due to their small size, and also much harder to clean (Kommedal, 2018).

Recently, in February 2020, a single spill of white pre-production polypropylene pellets (isotactic polypropylene; Sørensen and Almås, 2020) occurred when the MV Trans Carrier was transiting from Rotterdam to Stavanger and encountered a storm. This led to a total loss of around 13.3 tonnes of pellets (~470 000 000 individual pellets) in the Skagerrak. The spill accounted for 50% of the original tonnage (26 tonnes).

Pellets were quickly found washed onto Norwegian beaches[10], as well as the west coast of Sweden. Since then, approximately 700 beaches, spanning from the Oslofjord to Arendal (**Figure 14**), have been reported to receive these pellets. At the time of writing, 160 beaches have been cleaned – requiring more than 7 000 person-hours (October 2020, personal communication Oslofjordens Friluftsråd). In total 3 200 kg have been removed from the environment, meaning that 10 000 kg or 480 million pellets remain in the environment.

[10] First beach reported was Hankø, Outer Oslofjord

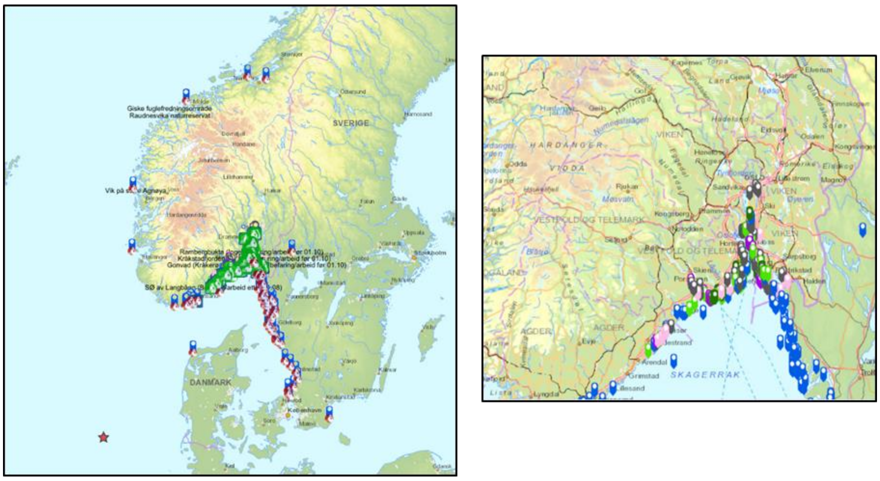


**Figure 14.** Location of the MV Trans Carrier spill in February 2020 (star) and locations on the Nordic shoreline where pellets have been reported, obtained from Norwegian Coastal Administration[11] 24th October 2020

### 7.2.2 Operational discharges

<u>*Description:*</u> Maritime vessels routinely discharge wastewaters, ballast waters and bilge waters. Wastewater are usually categorized as grey or black water. Grey water comprises of non-sewage wastewater such as those from sinks, showers, kitchens and laundry facilities whereas blackwater comes from onboard sewage (Lindgren et al., 2016). These discharges are regulated through international standards under Annex IX of the International Convention for the Prevention of Pollution from Ships (MARPOL).

Operational discharges have the potential to release microplastics directly into Norwegian waters. For example, discharges from grey waters are related to the washing systems on vessels and may thus include micro-fibres from the washing of textiles, or plastic abrasive scrubs used in cosmetics (e.g. Almroth et al., 2018; Guerranti et al., 2019; Cesa et al., 2017). Sewage and grey waters may be of greater concern for cruise ships relative to other seagoing vessels, large numbers of passengers and the volume of waste the produce.

Under normal operations, black water must be discharged at port-based facilities although grey water can be discharged into the marine environment following MARPOL regulations. For example, vessels exceeding 400 GTs or carrying more than 15 passengers can discharge untreated sewage at a minimum distance of 3 NM from the nearest land, although stricter requirements are in place for vessels operating in special areas – such as the Baltic Sea.

Cruise ships, large tankers and bulk cargo carries use huge amounts of ballast water to stabilise the vessel. Water is taken in one region and discharged in next port of call. In this context these discharges are not a source of microplastics but can contribute to the distribution of microplastics between ports.

<u>*Identification of industries or sectors linked to the product / release:*</u> Maritime traffic – commercial, ferries, military

[11] https://beredskap.kystverket.no/plastpublic/transcarrier

*Discharge from product lifecycle*: Use, end of life

*Quantity calculation given by weight and number of particles:*

**There is currently no data available to estimate the amount of microplastics entering the Norwegian environment through operational discharges.**

A single person on a cruise ship is estimated to generate between 120 and 300 litres of grey water per year which is usually the largest proportion of wastewater generated on cruise ships (Butt, 2007). However, it is not clear what percentage of grey water consists of microplastics and the discharges will vary per vessel type.

*Microplastic polymer composition:* The polymers identified in laundries will be as varied as the textile types. There have been no studies related to ship laundries however polymer compositions presented in studies of clothing washing include: PET, polyacrylic, PA (nylon) (Almroth et al., 2018). Indeed, PE/PET, PP were amongst the most numerous polymers were identified in sludge from WWTPs in Norway, and polymers identified in the Norwegian marine environment have been posited to originate from WWTP effluent (Lusher et al., 2015; Granberg et al., 2019; von Friesen et al., 2020).

Similarly, there are many polymers used in cosmetic scrubs, although PE is by far the most commonly used (Guerranti et al., 2019; Godoy et al., 2019; Piotrowska et al., 2020).

*Microplastic size range:* There have been no studies specifically addressing the release of particles from grey waters of vessels. Although sizes ranges from domestic laundries show that fibres can be as small as the LOD to > 2 mm (e.g. De Falco et al., 2019)

Size ranges of plastic scrubbers could be as small as 8 µm to 2 000 µm (Guerranti et al., 2019). A study which utilised beads obtained from toothpaste in Norway reported a size range of 50 µm – 590 µm (Bråte et al., 2018b).

*Associated additives:* One can assume that the list of plastic associated additives in operational discharges would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***

The only information pertaining to the release of microplastics from operational discharges are brief mentioned in literature reviews, or that can be inferred from shore-based laundries (**Table 18**). **Therefore, the data quality assessment score applied to operational discharge is: 13**

**Table 18.** Data Quality and Assessment Score for operational discharge.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |

| | | | | | |
|---|---|---|---|---|---|
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* The release of plastics and microplastics through operational discharges can be defined to source but there is no information on the quantities discharged. Therefore, the following information is required:

- Volumes of grey and black water discharges from vessels divided by vessel category

Summaries of literature confirming the presence of microplastics related to source: There is currently no information directly related to operational discharges as a source of microplastics to the marine environment. An estimated 10% of sewage that should be delivered on land is not received by port reception facilities (GESAMP, 2020) leading to a possible waste gap of 136 000 m$^3$.

### 7.2.3 Dumping

*Description:* The dumping of solid waste including plastics from vessels is prohibited under MARPOL 73/78, as well as the London Convention and London Protocol. However, illegal dumping, or accidental dumping may still occur. Therefore, if not handled appropriately waste can be directly input to the marine environment. This is an example of larger plastic items that can break down into microplastics once in the environment. The discharge of waste generated on ships is governed by regulations in Annex V of MARPOL – prohibiting discharge of waste into the sea except for food waste, animal carcasses, non-harmful cargo residues, cleaning agents and additives. In terms of cruise ship waste, 75% is generally incinerated on board or offloaded into port-side facilitates. That said, sometimes the facilities are not adequate to do so (GESAMP, 2020).

*Identification of industries or sectors that can be linked to release:* Maritime traffic – commercial, ferries, military, recreational

*Discharge from product lifecycle*: End of life

*Quantity calculation given by weight and number of particles:* **There is currently no data available to estimate the amount of plastics and microplastics entering the Norwegian environment as a result of dumping at sea.**

*Microplastic polymer composition:* One can assume that the list of plastic polymers in solid plastic waste is diverse therefore an exhaustive list is not included here.

*Microplastic size range:* Microplastics will be generated through the breakdown of larger plastic items and will represent a range of sizes.

*Associated additives:* One can assume that the list of plastic associated additives in plastic waste would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
There is limited information on the release of large plastic items through dumping, or accidental loss (**Table 19**). Much of the information is derived from observation on shorelines after loss. Some studies

have inferred sources mainly pertaining to fisheries activities in Northern Norway. **Therefore, the data quality assessment score applied to dumping is: 9**

**Table 19**. Data Quality and Assessment Score for dumping.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* Many of the waste categories covering dumping at sea have been categorised (GESAMP, 2020), however few studies exist which limits the comparative evaluation of this as a source for micro- and macroplastics. The only available information is what is washed up on shorelines, but it is not possible to refer this to the source of dumping.

Estimates of the discharge volumes would be required to understand this as a source to Norwegian waters. More information is required on the generation of microplastics due to weathering of discarded plastic items.

Summaries of literature confirming the presence of microplastics related to source: Some items plastic items found on beaches have been linked to shipping related activities. There are few studies looking at the discharge of waste or dumping from maritime traffic in Norwegian waters. The most extensive assessment of items possibly dumped or anciently lost from vessels was conducted by SALT (Falk-Andersson and Strietman, 2019). A deep-dive of litter washed up on beaches in Svalbard found that much of the large macroplastics could be identified either to brand or nationality, however origin could not be assumed as items purchased in one area might not be used in the same area where it has been released into the sea. Interestingly, most of the items related to cosmetics (shower gels, deodorants) were primarily associated with male consumption, leading to the authors of the report to suggest that this could be linked to fisheries due to the abundance of male fishing crew (Falk-Andersson and Strietman, 2019). Further, many items can be grouped into galley waste, domestic waste from crews, maintenance wastes, packaging and wrecked – container items. Some studies pointing at international shipping as a source for beached litter and seabed litter include Ryan et al. (2019), Nelms et al. (2020) and Ramirez-Llodra et al. (2013).

### 7.2.4 Shipwrecks

*Description:* Ships sink as a result of bad weather, armed conflict and human error (GESAMP, 2020). Abandoned boats are another common and growing problems on foreshores, beaches mudflats, marines in coastal regions around the world (Eklund, 2014). Boats that have been damaged, are commercially obsolete, or no longer wanted, affordable or reparable can be grounded or sunk, or are abandoned in intertidal zone. Shipwrecks can be a direct source of plastics and microplastics to the marine environment.

Shipwrecks and abandoned ships as a source of marine litter is little studied (Avio et al., 2017; Galgani et al., 2000; Turner and Rees, 2016). However, it is right to assume that boats can contained varying degrees of plastic items including paints and EPS which are fixed or contained within boats. Furthermore, many vessels are constructed with fibre reinforced plastic (FRP), also known as fibreglass. When these vessels wreck, they have the potential, and will, breakdown overtime generating fragments and microfibres.

When ships are wrecked, or accident occur, the ship owners (and/or their insurance company) are obliged to provide a detailed overview of all contents, inventory (including paints on the hulls and other surfaces) and cargo of any significance which were onboard the ship at the time of the accident. The information reported related to contents, inventory at the time of shipwrecks could be used to be used to make an initial risk assessment of the situation and as basis for the decision making of how to handle the situation in the short-term aftermath of the wrecking event. Decommissioning at coastal sites is addressed separately as a source (Section 7.4).

*Identification of industries or sectors that can be linked to release:* All maritime vessels – commercial, ferries, military, recreational

*Discharge from product lifecycle*: End of life

*Quantity calculation given by weight and number of particles:*

**There is currently no data available to estimate the amount of plastics and microplastics entering the Norwegian environment following shipwrecks.**

*Microplastic polymer composition:* One can assume that the list of plastic polymers in solid plastic waste is diverse therefore an exhaustive list is not included here.

*Microplastic size range:* Microplastics will be generated through the breakdown of larger plastic items and will represent a range of sizes. The most common size reported by Avio et al., 2017 was 0.5 – 1 mm.
*Associated additives:* One can assume that the list of plastic associated additives in plastic waste would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
There is no information on the release of plastics from shipwrecks in Norway (**Table 20**). **Therefore, the data quality assessment score applied to shipwrecks is: 17**

**Table 20.** Data Quality and Assessment Score for shipwrecks.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |

| | | | | | |
|---|---|---|---|---|---|
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* Shipwrecks can be composed of a variety of materials including plastics. Unfortunately, it is hard to make assumptions without knowledge of the types of vessels wrecked in Norwegian waters. Therefore, the following information is required:

- Number of shipwrecks in Norwegian waters
- Types of vessels and description of plastic components.
- Estimates the generation of microplastics due to fragmentation of plastic components.

The information reported related to contents, inventory at the time of shipwrecks could be used to be used to estimate the plastic components, and this the subsequent breakdown and release of microplastics.

Summaries of literature confirming the presence of microplastics related to source: Shipwrecks and abandoned ships as a source of marine litter is little studied (Avio et al., 2017; Galgani et al., 2000). An inventory in two estuaries in England show a variety of vessels items reported associated with each boat, including paints, EPS and other plastics fixed of contained within boats (Turner and Reese, 2016).

### 7.2.5 Recreational Boating

*Description:* Recreational boating which includes sea-based leisure activities and fishing, can contribute to the release of macroplastics through littering and accidental loss of items, although it is complicated to differentiate the exact source. Much of the items associated with recreational boating include user products, plastic bags, food packing containers, bottles and fishing gear (UNEP, 2009; GESAMP, 2020). Littering includes the direct disposal of macroplastics into the marine environment, the transport to and from coastal areas (shorelines) related to water movement and wind. Items can wash up on beaches, disperse within the water column and ultimately sink to the seafloor. As already mentioned, the weathering of paint on recreational vessels will also contribute to the release of microplastics (Section 7.1.2).

*Identification of industries or sectors that can be linked to release:* Tourism, recreation

*Period in life cycle that discharge occurs*: Use, end of life

*Quantity calculation of source:* The loss of macroplastic items to the marine environment through recreational boating are hard to quantify. Thus, the quantification of microplastics release is even harder without knowledge of degradation times in the marine environment.

**It is not possible to provide these values as there have been no dedicated studies on microplastics generation from the loss of macroplastics items.**

*Microplastic polymer composition:* There are a few reports on the identification of macroplastic items in the Norwegian marine environment which could have derived from recreational boating in the marine environment. PE and PP were dominant polymers on the beaches Nordre Langåra and Akerøya (>80% of polymer composition). Other identified polymers included PS, PVC, PET, acrylic, PUR and polyamides (Bråte et al., 2019).

Following degradation one can assume that microplastics derived from these materials will have the same polymer composition.

*Microplastic size range:* There have been no studies specifically addressing the release of particles from generated from macroplastic litter items.

*Associated additives:* One can assume that the list of plastic associated additives from the breakdown of littered items would be as diverse as the list of polymers, therefore an exhaustive list is not included.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
The currently available data is not enough to provide a solid estimation of the breakdown and consequential release of microplastics from littered items. The best available data related to the identification of macroplastic items reported on Norwegian shorelines. Far less information is available on the "at-sea" occurrence of macroplastics (**Table 21**). Furthermore, any microplastics identified to be fragments of larger plastics cannot be sources to their origins, the closest one can achieve is the polymer make up. In most instances polymeric make up is diverse with several possible sources. **Therefore, the data quality assessment score applied to microplastics derived from littering is: 10**

**Table 21.** Data Quality and Assessment Score for microplastics derived from littering.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* Litter items are regularly reported on shorelines but assigning them specifically to recreational boating activities is challenging. It is better to focus on understanding the generation of microplastics from these littered items.

- Breakdown of littered items under environmental for multiple types of plastics.

Summaries of literature confirming the presence of microplastics related to source: A study in the North Sea found that 7% of items were from recreational boating (Schäfer et al., 2019).

There are limited reports of microplastic in the Norwegian marine environment (Bråte et al., 2017), of the available information, none provide information pertaining to microplastics generated through recreational and littering activities

Conversely, there are numerous reports of macroplastics in the Norwegian marine environment. Studies from beaches reported that plastics dominated in datasets (75% – 99% material composition) (e.g. Falk-Andersson and Strietman, 2019). Recreational plastics have been reported at similar levels as fisheries items (Falk-Andersson et al., 2019).

It is not possible to infer microplastic generation from the input of macroplastic items in Norway due to the complex nature of weathering and environmental degradation (as discussed in Section 7.1.2). Furthermore, it is not possible to differentiate the source of user products present in the marine environment. The complex nature of water dynamics in coastal and offshore areas can facilitate the flux of items on and off the shore (Haarr et al., 2020).

Some data on macroplastics fragmentation under environmental conditions has begun to emerge, such as the breakdown of HDPE films from plastic shopping bags and other plastic materials (Kalogerakis et al., 2017; Iniguez et al., 2018; Turner et al., 2020). These studies reported changes in physical and chemical properties including molecular weight – denoting degradation through fragmentation.

## 7.3 Ports, marinas, shipyards

Ports, marinas and shipyards are considered as potential ocean-based sources of microplastic. This source category can be subdivided into different activities which generate microplastics: i) the release of microplastics from vessel maintenance (incl. paints from abrasive scrubbing), ii) the weathering of boat hulls and related aquatic structures (buoys, docks and pontoons and iii) dredging. Microplastics may be derived from all these activities. As an example, paint particles of various sizes and colours are often observed in the vicinity of boat moorings and boat maintenance facilities (e.g., Singh and Turner, 2009).

According to Kystverket, the Norwegian Coastal Administration, there is a network of 32 main ports around the Norwegian coast where one or more terminals are connected to the main network (**Figure 15**). There are approximately a further 600 state fishing ports which are managed by Kystverket and approximately 1 000 marinas have more than 20 permanent places for leisure boats (COWI, 2019).

Unfortunately, much of the debris items found in marinas could come from any source of human activities and it is therefore important to try to discern between land- and sea-based released (GESAMP 2020).


**Figure 15**. Map of the main ports located on the coast of Norway. The base map was modified from Norge Digital. https://kartkatalog.geonorge.no/metadata/norwegian-counties-and-municipalities-2020-clipped-by-coastline/7408853f-eb7d-48dd-bb6c-80c7e80f7392

### 7.3.1 Vessel maintenance

*Description:* Martine coatings are applied to all parts of a vessel for protection. This includes the hull, external decks and superstructures, as well as on-deck equipment. Routine maintenance is required for up-keep. In most instances, this can be yearly cleaning of boat hulls and the reapplication of coatings following abrasive scrubbing. Modern epoxy based maritime paints emit particles fulfilling the microplastic definitions when spilled during application or removed during abrasive blasting (Sundt et al., 2014). These activities have the potential to release fragments to the surrounding areas, including dry docks, quays and marinas. Vessels and other structures are recoated, and the original coasting often removed using abrasive scrubbers. These activities generate paint flakes that can lead into the environment. Paint flakes may enter the marine environment during maintenance and can transfer from waterside facilities including boat yards and dry docks. The high density of paints means that they sink rapidly and are likely to not be moved far from source locations.

There are approximately 321 000 motor and sailboats with fixed docks in marinas which probably require regular maintenance. Many marinas have ramps and slipways, and about 25% of the recreational marinas in Norway have cleaning locations for vessel maintenance (COWI 2019).

*Identification of industries or sectors that can be linked to release:* Shipyards, maintenance facilities, ports, dry docks, marinas

*Period in life cycle that discharge occurs:* Use, maintenance

*Quantity calculation of source:* As reported in Section 7.1.1, the only information available are estimated for recreational vessels.

The routine maintenance and cleaning of recreational vessels may be release 43 tons of microplastics into the Norwegian marine environment each year. Each leisure boat may release 0.18 kg if microplastics are generated during maintenance and cleaning. Scaling this up to the 321 000 leisure boats requiring a fixed dock in Norway, this equates to approximately 88 tonnes of microplastics per year (COWI, 2019).

**It is not possible to update these values for commercial vessels as there have been no dedicated studies to microplastics generation during vessel maintenance.**

*Microplastic polymer composition:* PUR and other acrylic resins are commonly used for paints and boat varnish. Other antifouling coatings have been developed which include biocidal coatings which are listed as CDPs, SPCs and Hybrid SPCs (Demierl, 2018).

Blasting abrasives which are used to clean the bottom of vessels have many different polymers including acrylic, PE, PA, PC, PUR (Galafassi et al., 2019).

*Microplastic size range:* There have been no studies specifically addressing the release of particles during vessel maintenance, however, Haave et al. (2019) identified PUR particles in the size range 11 – 300 µm in sediments from Bergen Fjord. These sources of these paint particles could also be related to maritime activities within the fjords or coastal industries.

*Associated additives:* Vessel paints are a complex mixture of polymers and ancillary compounds. Such ancillary compounds can include anti-corrosion pigments, UV resistance, and antifoulant compounds. Many of the non-polymeric compounds can be considered environmentally hazardous, including TBT, chlorothalonil, chromium trioxide, copper pyrithione, copper thiocyanate, dichlofluanid, diuron, folpet, Irgarol 1051, DCOIT (Sea-Nine 211), TCMS pyridine, TCMTB (Busan), Tralopyril, Zinc pyrithione, Zineb, Ziram (Thomas and Brooks, 2010; Tornero and Hanke 2016).

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
The currently available data is not enough to provide a solid estimation of the release of microplastics through vessel maintenance (**Table 22**). The only data available is derived from estimates and has not been verified with a study to monitor loss of particles during vessel maintenance. **Therefore, the data quality assessment score applied to vessel maintenance is: 7**

**Table 22.** Data Quality and Assessment Score for vessel maintenance.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* To support calculations, precise emissions from cleaning (generation of paint particles), and application (spillage) are required. The data is also weighted toward recreational vessels. Currently there is no information on commercial vessels

Summaries of literature confirming the presence of microplastics related to source: Discussed in Section 7.1.1.

### 7.3.2 Weathering / wear and tear

*Description:* Exposure to environmental conditions and wear and tear, can lead to the release of microplastics within ports and marinas. One example of weathering is the impact of boat hulls onto pontoons and other solid structures. The hulls of vessels are subject to constant wear and tear, caused by contact with harbour walls, other vessels and other installations. These activities cause paint to deteriorate and flake (Section 7.1.2, **Figure 16**). The use of ropes and moorings can also release fibres during use. Pontoons often include rubber structures (incl. used tires) to protect the walls from vessel impact, and thus themselves can further be a source of contamination. Microplastics can be released directly into the surrounding environment. High density particles will sink rapidly sediment and thus not move far from their sources, whereas lighter items could move away from source locations. Weathering of boats and harbour structures can also be discussed as a form of degradation, with factors which are most relevant to the ports and harbours being physical stress and salinity. For a full review on the complex nature of degradation in the marine environment we refer the readers to Booth et al., (2017) and Jahnke et al., (2017).

**Figure 16. A weathered mooring. Photo: Amy Lusher**

*Identification of industries or sectors linked to release:* Harbours and other activities

*Discharge from product lifecycle*: Use

*Quantity calculation of source:* No field studies concerning degradation rates of plastics and macroplastics performed in the Norwegian marine environment were available (Booth et al., 2017). Without a thorough understanding of the rate of weathering on plastic items it is not possible to calculate the number of particles entering ports and harbours.

**There is currently no data available to estimate the amount of plastics and microplastics entering the Norwegian environment from weathering of equipment in ports and harbours.**

*Microplastic polymer composition:* Plastic polymers related to weathering will cover a wide range of polymers as there are many different plastic components, one can assume paint (as mentioned in Section 7.1), fisheries related items (discussed in Section 7.5). Bråte et al. (2020) suggested that the rubber-like particles identified in mussels from Akershuskia originated from the tyres used as fenders on pontons or vessels. Polymers identified in other samples from the Norwegian environment include oxyresins, such as ethoxy resin, EVA, phenoxy resin, or particles containing BPA.

*Microplastic size range:* There have been no studies specifically addressing the size of microplastics released through weathering in Norway. Although, the studies which have identified microplastics in the environment ranging in size from 11 µm (limit of detection) to >5 mm (e.g., Bråte et al., 2018a, 2020; Haave et al., 2019; Peekan et al., 2019).

*Associated additives:* One can assume that the list of plastic associated additives from weathering would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
The currently available data is not enough to provide a solid estimation of the release of microplastics through weathering (**Table 23**). There is some information on weathering in the environment, but this is not related to maritime activities, rather the breakdown of litter (e.g., Iniguez et al., 2018; Turner et al. 2020; Kalogerakis et al., 2017). The information of recreational vessel weathering to release microplastics from maritime paints and antifoulant paints is a small proportion of the potential weathering in ports and harbours. **Therefore, the data quality assessment score applied to weathering is: 11**

**Table 23.** Data Quality and Assessment Score for weathering in ports and harbours.

| Score | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* A dedicated research effort is recommended to understand weathering from different sources within ports and harbours. This includes the release of particles through weathering under Nordic conditions. Currently the available data focuses on the weathering of boats, especially recreational vessel (COWI, 2019) but we do not have retrospective values on marine structures.

Summaries of literature confirming the presence of microplastics related to source: Discussed in Section 7.1.2

### 7.3.3 Dredging

*Description:* Ports and harbour facilitates are regularly dredged to remove the build-up of sediments and other material for the seafloor in order to maintain sailing depth. Activities include maintenance of navigation channels, construction project or the redevelopment of existing harbour facilities, or the removal of contaminated sediment (GESAMP, 2020). Contamination of sediments including with chemicals and plastics (macro and micro) may originate from a variety of sources including from industrial, commercial and leisure activities as well as surface runoffs within ports, harbours and marinas. Dredged sediment is deposited either at land deposit sites or sea deposit sits through dumping. Dredging is responsible for by far the highest volumes and tonnage of waste being dumped in the oceans around the world (GESAMP, 2020). The dredging and dumping of contaminated sediments are covered under the London Convention.

Dredging activities can facilitate the transport of plastics (macro and micro) – which have been incorporated into sediment – to other marine areas, for example from industrialized ports and estuaries to less contaminated areas. Unfortunately, research focused on the interconnection between dredging and plastic pollution is almost non-existent (GESAMP 2020).

*Identification of industries or sectors that can be linked to release:* Harbours and other activities

*Discharge from product lifecycle*: End of life, remobilisation

*Quantity calculation of source:* Volumes of sediment dredged in Norway are not recorded. There are many local dredging operations and not centralised. Operations do require a permit, but this is not registered (to our knowledge).

**There is currently no data available to estimate the amount of plastics and microplastics introduced to Norwegian waters through dredging in ports and harbours.**

Without an understanding of the numbers of plastics and microplastics incorporated into sediments it is not possible to calculate the number of particles which can be mobilised through the process of dredging.

*Microplastic polymer composition:* One can assume that the list of plastic polymers derived from dredging would be diverse and complex as there are many sources of particles to the marine environment, therefore an exhaustive list is not included here.

*Microplastic size range:* There have been no studies specifically addressing dredging and the size of plastics identified in sediments.

*Associated additives:* One can assume that the list of plastic associated additives from dredging would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
The currently available data is not enough to provide a solid estimation of the release of microplastics through dredging (**Table 24**). **Therefore, the data quality assessment score applied to dredging is: 20**

**Table 24.** Data Quality and Assessment Score for dredging.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* Survey of dredged material for plastic content should be conducted before an estimate can be carried out.

*Summaries of literature confirming the presence of microplastics related to source:* There is no literature confirming dredging is a source of microplastic (or macroplastics). From the available literature, it is realistic to assume that when plastics have settled to sediment – which is the ultimate sink for microplastics (Booth et al., 2017) – then these particles may be remobilised through the activity of dredging. Once example of sediments from Bergen harbour showed high concentrations of microplastics (Haave et al., 2019), therefore there is a potential for remobilisation, especially when harbours are regularly dredged to remove contaminated sediments or clear channels.

## 7.4 Decommissioning

*Description:* When vessels, offshore installations and coastal buildings are no longer in use they are decommissioned and broken down into salvageable and waste materials. During this process microplastics and other plastic materials may enter the marine environment as facilities are often located close to aquatic areas. Decommissioning – also known as ship breaking – has great economic benefits but generates substantial hazardous materials (including asbestos, insulation materials, sealants, plastic components, paints and associated contaminants) which can be identified in the surrounding environment (Rizvi et al., 2020; Du et al., 2018). In areas of high ship-breaking activities, plastics have been reported to contribute up to 50% of the total waste material (e.g., Reddy et al., 2003, 2004). Thus, the release of microplastics and further degradation of plastic items will occur (as observed by Reddy et al., 2006)[12].

Most decommissioning of commercial ships occurs in South Asia on exposed shorelines (UNEP, 2016). In Europe and the European Free Trade Association (EFTA) regions, there the Community waste Legislation has been applied to the management of ships which become waste. Further, the Water Framework Directive (WFD, Directive 2006/12/EC) sets out requirements to safeguard the environment and the Waste Shipment Regulation, sets the requirements for management and shipments of end-of-life vessels (Stuer-Lauridsen et al., 2007). End of life vessels, especially fibre reinforced plastic (FRP) vessels, presents a further challenge as the extent to which they are disposed or dumped is unknown. In Norway, at least in the past, some permits were issued for the disposal at sea of small plastic boats in 1997 and 2003 (GESAMP, 2020). Norway ceased dumping at sea of all vessels in 2004 (GESAMP, 2020).

Other decommissioning activities include that of offshore platforms which will also likely generate plastics and microplastics. When these infrastructures are no longer in use, the facilities must be removed in their entirety and decommissioning usually follows landing for scrapping, recycling and disposal. Norway currently has five onshore facilitates to accept offshore installations or components of them[13].

*Identification of industries or sectors that can be linked to release:* Maritime and decommissioning facilities on the Norwegian coastline.

*Discharge from product lifecycle*: end of life.

*Quantity calculation of source:* There is currently no data available to estimate the amount of plastics and microplastics entering the Norwegian environment from shipbreaking and other decommissioning activities. There appear to be approximately 10 companies potentially engaged in decommissioning of maritime vessels and offshore platforms in Norway. Plastics generated through decommissioning are not a component required to be reported through NorskUtslipp.

*Microplastic polymer composition:* Plastic polymers related to shipbreaking and other decommissioning activities will cover a wide range of polymers as there are many different plastic components, one can assume paint (as mentioned in Section 7.1), fisheries related items (discussed in Section 7.5). Plastic fragments identified in a ship breaking yard in India were identified as thermocol, styrofoams, nylon, transparent plastics, coloured plastics and glass wool (Reddy et al., 2006).

[12] These reports are from areas with high intensity ship breaking activities, and those along Norway's are not at this large scale
[13] https://www.norskpetroleum.no/en/developments-and-operations/cessation-and-decommissioning/

*Microplastic size range:* There have been no studies specifically addressing the release of particles in decommissioning yards in Norway.

*Associated additives:* One can assume that the list of plastic associated additives in a shipbreaking yard would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
There is no published literature of plastics released during decommissioning in Norway (**Table 25**). The only available data comes from the Asian industrial shipbreaking facilities (Reddy et al., 2006). **Therefore, the data quality assessment score applied to decommissioning is: 20**

**Table 25.** Data Quality and Assessment Score for decommissioning.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:*
- Description of plastic release from shipbreaking in a Norwegian facility
- Environmental study looking at the catchment of shipbreaking facilities

Summaries of literature confirming the presence of microplastics related to source: Shipbreaking produces marine litter including PVC, solid foams (Du et al., 2018). Similarly, in vessels that have been abandoned there is a clear potential for plastic residues to remain onboard at the time of disposal at sea. In the case of FRP vessels. This is a potential for a source of plastic litter when the structure degrades (IMO, 2019b). There is paucity of data here, but legitimate concerns (GESAMP, 2020).

There are no studies from Norway related to decommissioning of maritime vessels and structures. One study from the UK identified that antifouling paint particles (500 µm – 2 mm) in estuarine sediments in the vicinity of areas of vessel maintenance and vessel abandonment (Muller-Karanassos et al., 2019). Values for vessel abandonment had a maximal concentration of 400 particles $L^{-1}$ (4.2 g $L^{-1}$). Similar particles were also found in the guts of the deposit feeding ragworm, *Hediste diversicolor* (Muller-Karanassos et al., 2019). A study from India identified 81 mg of small plastic fragments per kg sediment, believed to have resulted directly from the ship-break activities at the site (Reddy et al., 2006).

The decommissioning of coastal buildings has been linked to high paint values in Sørfjorden, with high concentrations of PCBs in sediments matching those in biota, unfortunately it is not possible to infer any quantitative values related to microplastics (Russ and Green, 2002; Russ et al., 2005). Similar inferences have been made in Bergen, Drammen and Trondheim (Jartun et al., 2009; Jartun and Pettersen, 2010; Paetzel et al., 2003).

## 7.5 Fisheries

Fisheries rely on plastic materials – much of the equipment used is made from synthetic or semisynthetic materials which offer greater strength and durability than natural products. For example, synthetic fibres are cheap, durable and easier to handle than their natural counterparts. As a source category, fisheries can be subdivided into two categories which generate microplastics: i) the wear and tear of in-use gear leading to the formation of microplastics, and ii) the breakdown of fishing gear that is no longer in use, referred to here as ALDFG – abandoned, lost and otherwise discarded fishing gear.

Plastic materials are used in boat construction, boat maintenance, fishing gears (trawls, dredges, floats, lines, ropes, nets, lures, traps and pots), fish hold insulation and fish crates (**Figure 17**). Most fisheries activities use lines, cages or nets suspended from buoyant structure. The use of plastic materials provides buoyancy in many cases. A comprehensive assessment of the composition of fishing gears is presented in the Food and Agricultural Organisation (FAO) Technical Report on Microplastics related to Fisheries and Aquaculture (Lusher et al., 2017) and GESAMP WG 43 Second Interim Report (GESAMP, 2020). Lines, nets, and floats are made from a range of plastics – PP, PE, PVC, PS, and PA – whilst traps, dredges, lures, and lines also have significant plastic components. Plastic fish boxes and packing crates are typically made of PS or PE (Lusher and Welden, 2020).

Norway was estimated to us about 11 915 tonnes of fishing gear which represents approximately 25% of fishing gear used in Europe (Hann et al., 2018).

Unfortunately, a proportion of the materials used in fisheries will become marine debris (Lusher et al., 2017). Losses from of large items from fisheries are regularly reported in surveys on beaches (e.g., Falk-Andersson and Strietman, 2019; Deshpande et al., 2020 Unger and Harrison 2016;), floating on surface waters (e.g., Mcacfadyen et al., 2009) and located on the seafloor (e.g., Grøsvik et al., 2018). However, the generation of microplastics from active gear, or the breakdown of ALDFG is harder to quantify (Hann et al., 2018).

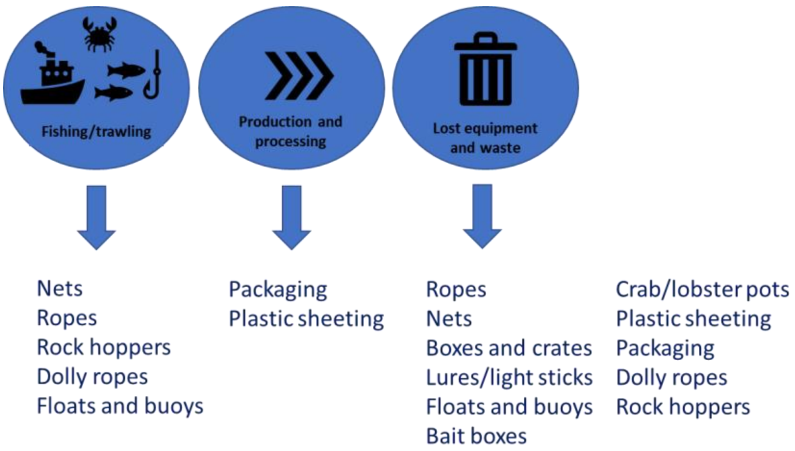


**Figure 17.** Fisheries activities that can contributes to release of microplastics to the marine environment. All microplastics released will be secondary.

### 7.5.1 Wear and tear from active gear

*Description:* When fishing gear is in-use it is exposed to many mechanical and environmental pressures which can weaken materials. Environmental weathering, biodegradation, and the wear and tear can result in the formation of microplastics. Unfortunately, identifying the proportion of microplastics which have originated from fisheries is challenging. Fishing gear which appears to have the potential for greatest contribution to microplastic to the ocean are nets used in benthic dredges and trawls, particularly the ground ropes (Lusher et al., 2017). For example, ground ropes – which are sacrificial ropes that protect the integrity of nets – are dragged in contact with the seabed for many miles and are subject to abrasion from benthic sediments or snagging and total loss. Such ropes are made of plastics and must be monitored and replaced as they wear away over time (Lusher et al., 2017). EUNOMIA reported that nets were at high risk of generating microplastics; ropes, floats, bottom gear, pots, sheeting, and paints were at medium risk; and, fishing line, fishing lures and bait boxes/packaging were at low risk (Hann et al., 2018).

*Identification of sector that can be linked to release:* Fisheries

*Discharge from product lifecycle*: Use

*Quantity calculation of source:* The degradation rates of fishing materials depends on may factors, temperature, exposure to sunlight and the structure of the polymers and chemicals (Booth et al., 2017). This makes a quantity calculation of microplastics released from active fishing gear challenging. Currently, the only available reference to potential annual loss in terms of the generation of microplastics is an estimate of 0.5% (Booth et al., 2017).

**There is currently no data available to estimate the amount of microplastics entering the Norwegian environment from fisheries gear.**

*Microplastic polymer composition:* One can assume that the list of plastic polymers related to fishing gear is diverse, the main polymers used in fisheries are PP, PE, PVC, PS and PA (Lusher et al., 2017).

*Microplastic size range:* Microplastics will be generated through the breakdown of larger plastic items and will represent a range of sizes.

*Associated additives:* One can assume that the list of plastic associated additives in fishing gear would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
There is limited information related to microplastic generation from active fishing gear, and what does exist is an estimation (**Table 26**). In an earlier report, Sundt et al., (2014) estimated that microplastics generated from the use of fisheries and aquaculture equipment could be between 1 000 and 10 000 tonnes a year. It has not been possible to update these values. **Therefore, the data quality assessment score applied to active fishing gear is: 10**

**Table 26.** Data Quality and Assessment Score for active fishing gear.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* There needs to be effort into the breakdown of fishing gears under Norwegian fishing conditions. The amount of gear replacement due to wore-out gear (not lost gear) could be used, however this does not help with the breakdown. Weights of gears before use and after replacement would give some indication of the generation of lost particles by mass.

*Summaries of literature confirming the presence of microplastics related to source:* Even though active fishing gear will generate microplastics, there are no global estimates of the amount of plastic and microplastics generated by the fisheries sector.

Some global investigations have suggested that microplastics identified in their samples originated from fisheries activities. For example, the morphologies of microplastic debris identified in the environment (fibres, fragmented debris) have been linked to local fisheries sources, including fishing gears, trawling activities and EPS buoys (reviewed in Lusher et al., 2017). Recently, a study focused on the Beibu Gulf, a fishing ground in the China-Indo Peninsula identified that PP and PE fibres were dominant, suggesting they might originate from the fishing gear. These fibres contributed to 61.6% of the overall microplastic abundance in sediments. There was also strong correlation to fishing yields in different districts – indicating that the different fishing activities influences the microplastic load in the region (Xue et al., 2020). Polyester and PE fibres (likely from fishing lines) and PVC strapping (likely linked to packaging activities) were found inside the stomachs of cod from the Norwegian coast (Bråte et al., 2016).

### 7.5.2 Abandoned, lost or otherwise discarded fishing gear (ALDFG)

*Description:* Abandoned, lost or otherwise discarded fishing gears (ALDFG) are considered the main source of plastic waste from the fisheries sector, but their relative contribution is not well known (Lusher et al., 2017). During normal fishing activities in surface and deep-water fishing gears can become stranded, break loose, or get lost as a result of weather, winds and currents (GESAMP, 2020). Further, loss of fishing gears can be a result of enforcement on fishers to abandon gears (e.g. illegal fishing or illegal gears), operational pressure (e.g. use of too much gear in restricted time periods) and environmental conditions (e.g. weather, seabed irregularities), lack of/inaccessible/expensive onshore gear and waste disposal facilities (reviewed in Lusher et al., 2017; GESAMP, 2020).

Most of this gear will float when made of low-density plastics – such as HDPE and EPS – whereas, entangled and ensnared gears are more likely to continue fishing on the seafloor until they are removed (Lusher et al., 2017). The FAO released a rough estimate of the loss of gillnets – equally about

1% of gear per vessel per year (Gilman et al., 2016). Globally 6% of all nets, 9% of traps and 29% of all lines are lost to the marine environment (Richardson et al., 2019). It has been estimated that Norwegian commercial fisheries alone generate 380 tonnes per year of marine debris from fishing gear (Deshpande et al., 2019).

Norway has a fishing fleet of about 6 000 commercial vessels, 5 500 are less than 15 m in length, 2250 15 – 25 m in length and 240 bigger than 256 m (Nordic Council of Ministers, 2020). There are regulations in place that require fishers to report any lost gear to the authorities.

Fisheries represent the dominant source of beach litter on the Norwegian coastline (Falk-Andersson and Strietman, 2019; Falk-Andersson et al., 2019; Earll et al., 2000; Bråte et al., 2019a; Haarr et al., 2019; Nashoug, 2017). ALDFG represents more than 75 percent of marine debris in the Norwegian continental shelf – a comprehensive analysis of floating macro-debris (> 200 mm diameter) revealed that 20 percent by number and 70 percent by weight was fishing–related, principally floats and buoys (Eriksen et al., 2014). Some items of marine debris can be directly sourced to trawling and commercial netting operations, and in some cases labelled pots and bait boxes can identify specific fisheries and home ports. For example, most of the plastic items collected from the beaches on Akerøya in the Outer Oslofjord were from fishing related activities including dolly ropes from bottom trawling (Bråte et al., 2019b). Calculating the generation of microplastics from these items is challenging.

*Identification of sector linked release:* Fisheries

*Discharge from product lifecycle*: Use, disposal

*Quantity calculation of source:* Although there is a good understanding of the presence of fishing gears in the Norwegian environment (e.g., Olsen et al., 2020; Falk-Andersson and Strietman, 2019), **there is currently no data available to estimate the amount of microplastics generated from the breakdown of ALDFG.**

Since solar radiation and thermal oxidation are the primary factors that promote the plastic degradation to smaller fragments, fishing equipment settled on the sea floor are unlikely going to be degraded, thus they are going to persist intact for decades (Macfadyen et al., 2009).

*Microplastic polymer composition:* One can assume that the list of plastic polymers related to fishing gear is diverse, the main polymers used in fisheries are PP, PE, PVC, PS and PA (Lusher et al., 2017).

*Microplastic size range:* Microplastics will be generated through the breakdown of larger plastic items and will represent a range of sizes.

*Associated additives:* One can assume that the list of plastic associated additives in fishing gear would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
There are many descriptions of ALDFG identified in the Norwegian environment, however the challenge is determining the degradation of these materials and the subsequent generation of microplastic (**Table 27**). **Therefore, the data quality assessment score applied to ALDFG is: 19**

**Table 27.** Data Quality and Assessment Score for the generation of microplastics from abandoned lost and otherwise discarded fishing gear.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* Understanding of generation of microplastics from the breakdown of ALDFG requires an understanding of weathering and environmental breakdown of different fisheries related items. Further research should be directed towards these investigations.

*Summaries of literature confirming the presence of microplastics related to source:* Even though the Norwegian commercial fisheries alone may generate 380 tonnes per year of marine debris from fishing gear (Deshpande et al., 2019) there is little evidence to show the generation of microplastics from these items. Bråte et al. (2016) identified polyester and PE fibres (likely from fishing lines) and PVC strapping (likely linked to packaging activities) inside the stomachs of cod from the Norwegian coast but as to whether they are the result of ALDFG or active gear is impossible to differentiate.

## 7.6 Aquaculture

*Description:* The aquaculture industry is, for the most part, sea-based and uses large amounts of equipment made of plastic that can tolerate the harsh salt environment better than most other alternatives. Aquaculture for finfish is conducted using net pens or floating sea cases – these are constructed with a "collar" floating at the surface where a net enclosure is suspended in the water column or made of enclosed and ridged floating materials which are anchored to prevent drift. Shellfish culture equipment is usually made of ropes hanging from floatation devices, either anchored to the bottom or attached to the seafloor, or in bottom cages. All systems incorporate ropes, buoys and mesh bags to some extent (GESAMP, 2020).

Due to wear and tear of larger plastic constructions (nets, cages, tubes, ropes in different sizes, buoys) and also smaller items which are frequently used for a variety of purposes (strips, tape, artificial kelp), aquaculture is a potentially large contributor to secondary emission of microplastic directly into the marine environment (Lusher et al., 2017). Three recently available reports addressed the subject of aquaculture-derived litter (Huntington, 2019; Sandra et al., 2019; GESAMP, 2020).

In Norway, Hognes and Skaar (2017) estimated the material use in plastic for aquaculture to be 192 000 tonnes. This estimation is based on the main plastic components usually involved in sea-based aquaculture facilities: moorings for floating collars and feeding fleets, nylon ropes, floating collars including walking rails, bottom rings, hamster wheels, nets, feeding hoses, sea-lice skirts, cleaner fish sheds, and other ropes not used for moorings (e.g., consumables, 10 – 30 mm). Compared to sea-based fish aquaculture, the use of plastics in kelp and blue mussel aquaculture is at a smaller scale. Both blue mussel and kelp aquaculture uses ropes placed in the marine environment and boat trafficking for maintenance, supervision and harvesting.

Microplastics may be released to the environment either directly through activities (wear and tear) or from loss of plastic equipment that breakdown into microplastics. Aquaculture can be divided into four main activity categories which all contribute to release of microplastic to the environment: production, operations, waste handling and household (**Figure 18**). Unfortunately, there is no clear generation of values related to each source.

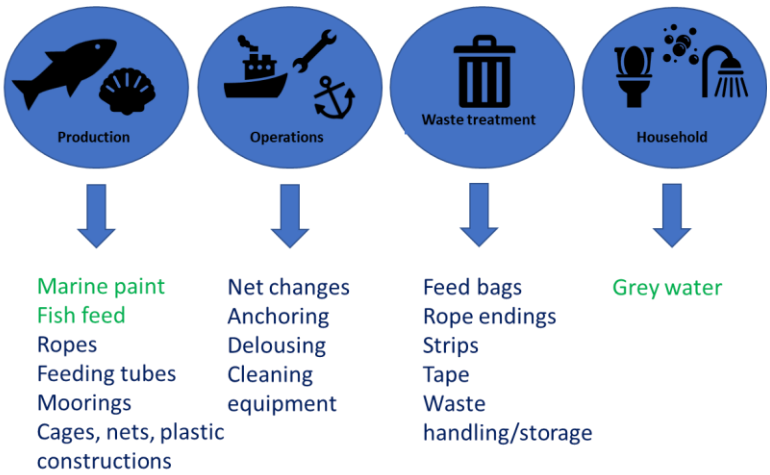


**Figure 18.** Aquaculture activity categories that can contributes to release of microplastics to the marine environment. Primary microplastics are depicted as green, secondary microplastics as blue.

***Production***: is the daily activities for maintenance of the living stock. Sources of microplastic include:
- Fish feed - both the raw material and finished fish feed products (Gomiero et al., 2020). *Any incorporated microplastics may be released through feed spills but also through the faeces of the fish.*
- Marine paint (Section 7.1.2) from boats that are used for work and deliveries on the facilities,
- Breakdown of the plastic equipment present in most sea-based aquaculture facilities. Microplastics may be generated through wear and tear of in-use equipment. Furthermore, the loss of plastic equipment to the environment – which is not retrieved - can become a source of secondary microplastics due to break down into smaller pieces. Poor weather conditions and storms increase the wear and tear of equipment and make work on the facility more challenging which also increase the potential for unintentional losses.

***Operations:*** includes the activities related to production including delousing, anchoring, net changes, cleaning of equipment. All operations are potential sources of secondary microplastics. High activity levels and equipment handling increase the likelihood loss of plastic containing equipment (rope, rope endings, cut off from feeding tubes, strips etc.). Identified sources include:
- Fish feeding tubes which can release microplastics through wear and tear when dry food for fish passes through the tube at high speed. Interestingly, both Vangelsten et al., (2019) and Gomiero et al., (2020) found that more microplastics were released from curved feeding tubes than straight tubes. Gomiero et al., (2020) also found that older tubes release more microplastics compared to newer tubes.
- Pressure washers are often used to clean nets of epifauna. This handling might cause the release of small fractions of plastic.
- Operations often requires the use of boats which may release paint particles (covered in Section 7.1.2).
- Biofilters are used for water quality systems in closed aquaculture systems – such as recirculating aquaculture systems (RAS). These biofilters are sometimes found as emission on beaches and in coastal areas. The release is unintentionally losses.
- Grey water emission from household activities might contain microplastic due to the direct and unfiltered release to the marine environment.

***Waste treatment***: is an activity that can potentially contribute with large amounts of microplastic.
- For example, handling and cutting of feeding tubes and used floating collars (filled with EPS), before transportation to a waste facility may generate secondary microplastics (in the form of shavings)
- Outside storage of equipment following waste handling is often observed along the coast and this is a potential source of plastic release to the environment either through accidental loss when not properly secured or through breakdown.

***Household:*** is related to the accommodation and feeding platform that are used for workers on aquaculture sites remotely located and that release emission directly to the sea.
- Household can be a primary source of microplastic to the marine environment due to drain age from dishwashers and industrial washing machines. Grey water (run off from dishwashers, washing machines and sinks) are released directly into the marine environment from the platforms, while sewage is collected and brought to the shore when combustion toilet are not used (personal communication, Robert Aavik - Emilsen Fisk AS).

*Identification of industries that can be linked to release:* Aquaculture

*Discharge from product lifecycle: use and end of life*

Secondary microplastic can be discharged into the marine environment at any time when the plastic equipment is in use at the aquaculture facility or in connection with it. The rate of discharge depends on the use, environmental impact that influence the wear and tear (UV radiation, wave action, etc) but in general the rate of discharge would increase with time spent in use (age) and exposed. The potential discharge of microplastics to the environment is especially high when an aquaculture site is fallowed, and all equipment is taken out of the sea. The activity level is high and a large part of the plastic containing equipment need to be cut into smaller units upon transportation to the waste facility.

Microplastic discharge from fish feed occur when feed is released into the water and when the microplastic from ingested feed particles is released into the water trough fish faeces. Microplastics from grey water emission can occur at any time the platform is manned.

*Quantity calculation of source:* The release of microplastics from feed tubs have been calculated using three different approaches, Naturvernforbundet[14] estimated a potential loss of approximately 325 tonnes of microplastics per year in Norway by weighing feeding tubes before and after use. Vangelsten et al. (2019) modelled in combination with information from aquaculture sites of the exchange frequency of feeding tubes and found the release of microplastics to be between 10 – 100 tons per year on a national basis in Norway. Whereas, Gomiero et al. (2020) performed an abrasion test of feeding tubes and estimated the microplastics release to be 150 – 569 kg per year per aquaculture site in Norway.

Secondary microplastics are the largest fraction of potential microplastics discharge from aquaculture to the sea. EUNOMIA (2016) suggested that 2 870 macroplastics were lost from global aquaculture operations annually.

There is sparse information related to weight, number and size of particles released from sea-based aquaculture. This is mostly due to the large degree of secondary microplastics release caused by tear and wear of equipment the size and weight of particles can vary a lot. Furthermore, Since the plastic polymers used across aquaculture facilities are not unique for the aquaculture industry it is hard to identify the origin of any microplastics found in the environment.

*Microplastic polymer composition:* At the broadest level, thermoplastics and thermoset plastics are used in the manufacture of aquaculture equipment – with elastomers to a lesser extent (GESAMP, 2020). A recently commissioned study summarising plastic composition of equipment used in aquaculture systems is presented in Huntington (2019) and reflected in the appendix (**Table 39**). Regarding a Norwegian context, microplastics have been identified in both the production and operation phases:

- ***Production***: PE, PA (from fish raw material), PP (contamination from production line) were identified during fish feed production, whilst PE, PA and PET was found to be major contributors in the finish fish feed product. PP (contamination from plastic bags) was also identified but not in raw material (Gomiero et al., 2020).

- ***Operations***: PE, PP, PA were reported as the most frequently used polymers at one aquaculture facility (Gomiero et al., 2020; pers comms – Noralf Rønningen, Scale AQ). Specifically, PE was found in floating collars, buoys in mooring systems, antifouling paint and

[14] https://naturvernforbundet.no/marinforsopling/flere-hundre-tonn-mikroplast-rett-ut-i-havet-article37577-3788.html

feeding pipes. Ropes from mooring systems, net enclosures, floating pontoon artificial kelp from cleaner fish sheds were found to contain PP while PA was found in ropes from mooring systems and in antipredator nets.

Unfortunately, there are no studies pointing to the polymers from ***household*** and ***waste management*** could be found.

<u>*Microplastic size range:*</u> There is sparse information of weight, number and size of microplastics from aquaculture. This is mostly because when microplastics are generated through by tear and wear of equipment the weight, number and size of particles can vary a lot. The study performed by Gomiero et al. (2020) identified particles in the size range 2.1 – 80 µm.

<u>*Associated additives:*</u> The list of associated additives from plastic products used in aquaculture is assumed to be diverse and an exhaustive list is not included here. Plastic products in aquaculture that is used for food have defined regulations.

<u>*Description of the uncertainty:*</u> ***Data source: Tier 1 – publications and reports, Tier 3 – personal communications***

Currently there are no estimates of the amount of plastics waste generated by aquaculture (Lusher et al., 2017), including Norway, which makes it challenging to calculate the generation and release of microplastics to the marine environment.

The available data is not enough to provide a solid estimate of the release of microplastics generated from aquaculture (**Table 28**). For example, Gomiero et al., (2019) only investigated one aquaculture facility and which might not be representative for all aquaculture facilities, feed producers and plastic equipment. The plastic material budget estimated in Hognes and Skaar (2017) is based on many assumptions. There is limited information related to microplastic generation from aquaculture facilities, and what does exist is related to one specific aquaculture facility. **Therefore, the data quality assessment score applied to is: 9**

**Table 28.** Data Quality and Assessment Score for microplastics derived from Aquaculture.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

<u>*Missing data required to provide greater certainty in values:*</u> The current available data is not enough to provide a solid estimate of the release of microplastics from aquaculture. Most urgently required are numbers pertaining to microplastics released as through weathering/breakdown of larger plastic equipment. A better overview of the actual amount of plastic equipment in use for aquaculture and

plastic accounting to be able to identify the amount of losses that has the potential to become secondary MP.

<u>*Summaries of literature confirming the presence of microplastics related to source*</u>: Studies and reports have identified the material flow in an aquaculture facility (Hognes and Skaar et al., 2017) and several potential sources for release of microplastics to the sea from the aquaculture industry (Sundt et al., 2014, 2016; GESAMP, 2015; Lusher et al., 2017; Gomiero et al., 2020). Gomiero et al. (2020) also identified the plastic polymers in some of the most frequent used plastic sources on an aquaculture facility and quantified the microplastic loss from feeding tubes, as well as the investigating fish feed as a source. Gomiero et al. (2020) also identified plastic polymers from sediment samples (38 – 920 particles/kg dry weight), suspended matter samples (220 000 – 360 000 particles/kg dry weight) and water samples in close vicinity to an aquaculture site. Nordlansforskning and Salt AS within the HAVplast project (Vangelsten et al., 2019) have developed a model to simulate release of microplastic from fish feeding tubes and quantified it to be 10 – 100 tons per year on a national basis.

Experience from the ongoing project "*Plast på avveie I havbruksnæringen i Trøndelag*" have shown that waste handling is very different between operators and companies where some of the activities related to clean up of a facility might cause large emission of secondary microplastic in the shoreline. Examples of this is the handling and cutting of feeding tubes which can be hundreds of meters in length. The tubes are divided into smaller units by various methods upon transportation to a waste facility. Some uses a mechanical cutter that generates minimal losses of plastic and some also uses chainsaws that produces large amount of plastic shavings that potentially can reach the sea. When the age of use for floating collars is reached, they are also divided into smaller units upon transportation to a waste facility. The practice here is also different between companies and even within companies, but there is a potential loss of plastic fragments during these operations and especially if this is done on the shoreline or close to the sea. The floating collar is filled with Styrofoam that is light weighted and easily spread with wind or currents.

## 7.7 Petroleum

*Description:* The petroleum offshore industry is a potential source of both primary and secondary emission of microplastics. Sundt et al. (2014) and (2016) found that drilling fluids based on plastic and microbeads in addition to Teflon strengthened particles have been used for drilling purposes for a few decades. Discharges from oil production and exploration in Norway are regulated according to national rules where all emission must be reported to the authorities annually. The substance's inherent ecotoxicological effect is used for classification where substances are classified into four categories of increasing severity (green, yellow, red and black). These effects are based on properties regarding biodegradability, bioaccumulation potential, toxicity and harmfulness to reproductive systems or as a mutagenic. Due to low grade of biodegradability, microplastics would be classified as category "red" that needs to be reported. In theory, it should be possible to quantify microplastic emissions. However, oil and gas operators have reported that there are unclear definitions of microbeads and microplastic that gives inaccurate reports of the actual emission. Sundt et al., (2016) reported that some of the substances used are perceived as not included in the definition and therefore suggests that discharges are higher than reported to the agency.

The OSPAR Commission (Protecting and conserving the North-East Atlantic and its recourses) have defined 59 functions related to the petroleum industry may contain microplastics. In 2016, the European Oilfield Chemical Speciality Association (EOSCA) identified 14 functions where products containing microplastics were utilized (**Table 29**).

**Table 29.** Functions where products containing microplastics have been used in the petroleum industry[15].

| | | | |
|---|---|---|---|
| 1 | Antifoam (Hydrocarbons) | 8 | Filtrate Reducer |
| 2 | Asphaltene Inhibitor | 9 | Fluid Loss Control Chemical |
| 3 | Cement or Cement additive | 10 | Gelling Chemical |
| 4 | Corrosion Inhibitor | 11 | Lost Circulation Material |
| 5 | Defoamer (Drilling) | 12 | Viscosifier |
| 6 | Demulsifier | 13 | Wax Inhibitor |
| 7 | Drilling Lubricant | 14 | Other – Friction/Drag/reducing agent |

**Primary microplastics** are added to chemicals for different reasons to enhance oil recovery. For **well drilling –** substances containing microplastics are added to drilling fluids when drilling fluids are being lost to fissures in rock formations or porous rock strata. The particles fill the fissures and pores. In **production**, demulsifies containing microplastic are added to the produced water during the separation process to break emulsions (neutralizing electrostatic charges). When microplastic polymers are used they are in the form of a dissolved in organic solvent. Microplastics are also found in **pipelines** as friction reducers. Polymers are added to exported oil for reducing operational pressure that makes systems safer, it reduces corrosion rates and energy requirements (and $CO_2$ emission) (EOSCA, 2016). Microplastic is also used as coating on proppants used in **well fracturing** (personal communication, Ystanes – Equinor). Primary microplastics used during drilling and in pipelines is normally not released to the environment due to closed processes/systems or collection of

[15] https://echa.europa.eu/documents/10162/23964241/15_eosca-robinson_en.pdf/7d9b28b2-715c-9a27-7b32-7875d9e92686

chemicals/fluids. Emission of microplastics from these sources would be in case of accidental spills or damage of equipment like fracture of pipelines. Produced water from production is a potential emission source of microplastics since this is released to the marine environment and potentially can contain microplastics

Plastic granules (powder granules) originating from **industrial washing machines** have been found on the seafloor probably released as grey water from the machines (personal communication, Ystanes - Equinor). Emissions of microplastics through grey water are released in connection to daily use.

**Secondary microplastics** are generated through break down, wear and tear of larger plastic products, but also unintentional loss. Plastic products that are in frequent use in offshore petroleum is strips, marking tags, gloves, tarpaulins, disposable equipment's both from the recovery of oil/gas and catering (personal communication, Ystanes – Equinor).

Sandblasting of offshore structures for maintenance can release paint containing microplastic directly to the sea if there is not an obligation to collect the waste product. Microplastics derived from paint that is either because of corrosion or removed during maintenance (sandblasting) are released directly to the marine environment unless there is an obligation to collect the waste product.

The pathways of release to are marine environment are**:** Drilling (& Completion/Workover) – No intended release, Production – Potential release via Produced Water, Pipelines – No intended release


**Figure 19.** Petroleum activity categories that can contributes to release of microplastics to the marine environment. Primary microplastics are depicted as green, secondary microplastics as blue.

*Identification of industries linked to the release:* *Oil and Gas*

*Discharge from product lifecycle*: Primary microplastics may be discharged during the entire lifecycle and release to the marine environment is mainly during handling, active use and end of life. Secondary microplastics are discharged mainly through active use and end of life

*Quantity calculation of source:* The OSPAR commissioning contracting parties with offshore industries is a reasonable estimate of total EU discharges, accounting for > 90% of all EU offshore oilfield industry discharges. Norway had in 2016, 46 installations with produced water release (OSPAR OIC, 2018).

Data for contracting partners in 2016 showed that 3252 different chemical products were used and 2439 of them were discharged. 71% of discharges were classified by OSPAR as PLONOR (substances that Pose Little or No Risk to the Environment, OSPAR OIC, 2018) and 115 products contained microplastics (3.5%) of which 82 products (2.5%) containing microplastics were discharged. Of the total 910 670 tonnes of chemicals products used, 1 948 tonnes were microplastics (0.2%). **Table 30** presents data on chemical discharges related to oil and gas industry from OSPAR commission contracting parties. In 2016, the total reported microplastic discharge was 487 tonnes (*102 tonnes if demulsifiers were excluded). This represents 25% (*5.2%) of all microplastic containing products used, 0.05% (*0.01%) of all chemicals products used, 0.16% (*0.03%) of total chemical discharges.

**Demulsifiers were identified as the largest contributor of microplastics in chemicals by Norwegian and UK partners in 2016* **(Table 31).** *It was also found that operators calculated discharge volumes differently – as demulsifier polymers are usually dissolved in organic solvents – leading to overestimates as these will partition to the hydrocarbon phase and not be discharged in produced water.*

**Table 30.** Data of chemicals containing discharged from the OSPAR commissioning contracting parties modified from EOSCA (2016). Data is presented Tonnes (T).

| | **Product use (T)** | **% microplastics** | **Reported discharge (T)** | **% Discharge** |
|---|---|---|---|---|
| All chemical products | 910 670 | 0.21% | 310 359 | 34% |
| Products containing microplastics<br>- *Excluding demulsifiers* | 1 948 | - | 487<br>*102* | 25%<br>*5.2%* |
| Products where no microplastic data was provided | 29 740 | - | - | - |

**Table 31.** Microplastic 2016 data of functional oilfield chemicals from Norway and United Kingdom modified from EOSCA (2016). Data is presented Tonnes (T).

| **OSPAR Function** | **Microplastics used (T)** | **Microplastics discharged (T)** | **% discharged** |
|---|---|---|---|
| **Demulsifier** | **1085.6** | **384.8** | **35%** |
| Wax inhibitor | 160.0 | 20.9 | 13% |
| Other chemicals | 122.1 | 2.0 | 1.6% |
| Corrosion inhibitors | 94.5 | 30.5 | 32% |
| Antifoam (Hydrocarbons) | 67.3 | 42.4 | 63% |
| Lost Circulation Material | 70.4 | 0.1 | 0.14% |
| Drilling lubricants | 45.8 | 0.1 | 0.22% |
| Defoamer | 36.5 | 2.3 | 6.3% |
| Fluid Loss Control Chemical | 30.2 | 0.0 | 0% |
| Asphaltene Inhibitor | 25.9 | 0.1 | 0.39% |
| Friction Reducing Agent | 17.4 | 2.5 | 14% |
| Viscosifier | 14.6 | 0.0 | 0% |
| Cement/Cement additive | 12.4 | 0.9 | 7.3% |
| **Total** | **1782.7** | **486.4** | **-** |

*Microplastic polymer composition:* There are many different polymers used by the petroleum industry and an extensive list is not included as actual discharges to the environment including the quantities found in the environment are not clear. Industrial abrasives include acrylic, melamine and polyester, PE, PVA and alpine drill beads are also a copolymer are added to cement (GESAMP, 2020).

Some polymers have been identified in sediment samples from close to oil and gas facilities (Arp et al., 2018). These include: PE, PP, PET, PU, PTFE, PS, PUF, PUC, PE:PP, PMMA, Polyacrylamide, Melamine etc. (Note: it has not been verified that these polymers originate from petroleum activities).

*Microplastic size range:* There was not found any available studies specifically addressing the release of particles for the Petroleum industry. However, in the petroleum industry water-soluble and oil soluble polymers are used, these polymers do not fit within the working size-definition of microplastics (0.001 – 5 mm).

*Associated additives:* One can assume that the list of plastic additives from Petroleum industry would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
There are few data that confirms or verify quantitative measures of microplastics emission from the Petroleum industry (**Table 32**). Data from sediment samples is sparse and the dataset is not statistically significant to verify Petroleum activities as a major source. Emission of microplastics are calculated differently between operators and the definition of microplastics does not cover all plastics which are in use. **Therefore, the data quality assessment score applied to petroleum activities is: 11**

**Table 32.** Data Quality and Assessment Score derived from the petroleum industry.

| Score | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Description missing data required to provide greater certainty in values:* Petroleum activities are an un-researched source, and there are few open access reports on the quantities of microplastics released from petroleum activities.

A common and proper definition of microplastics is important to incorporate all possible microplastics, including those which are in liquid form.

There is also a need for common approaches for calculating discharge volumes since they are calculated differently between the different operators. Microplastic emissions from abrasion and sandblasting of paint on offshore constructions that is done on a regular basis is not quantified and can be released to the marine environment if it is not demanded to collect the waist product. There is no data on the total emission from sandblasting operations for the petroleum industry.

*Summaries of literature confirming the presence of microplastics related to source*: EOSCA identified functions where products containing microplastics have been used in the petroleum industry. EOSCA also summarized the microplastics used and discharged for OSPAR commission contracting parties in 2016 (accounting for > 90% of all EU offshore oilfield industry discharges). Few studies are available for the quantification of microplastics released from the Petroleum industry. However, there are no published studies quantifying these releases.

Some studies have analysed sediment samples from the North Sea, central North Sea and Barents Sea for microplastics (amount, size and polymers, Moskeland et al., 2018; Arp et al., 2018). From these studies it cannot be concluded that the microplastics found were released from Petroleum activities, but higher (but not significantly conclusive) concentrations were identified at stations close to Oil and Gas installations compared to regional stations. The most commonly identified polymers were Chlorinated polyolefins (particularly chlorinated polyethylene), paint resins such as phenyl resin, rubber materials, polyacrylamides and PET.

## 7.8 Other offshore activities

There are several other offshore activities that are yet to be addressed related to plastic and microplastic pollution. GESAMP (2020) identified activities including:

- **Meteorological activities** – including weather balloon which have several plastic components – plastic boxes, latex balloons, polystyrene base and ropes – many of which are unlikely to be recovered from the environment if they travel far from site of release. There are ongoing discussions by meteorological institutions into how to improve this.
- Oceanographic instruments – including XBTs and other tags which are often deployed and not recovered.
- Fireworks
- Warfare and military activities.
- Windfarms

It is not possible to go into details here as there is so little information available. In the future, all offshore activities should be considered as sources of plastic pollution.

### 7.8.1 Windfarms

*Description:* Offshore windfarms are a valuable source of renewable energy, providing a sustainable source of electricity. Many of the windfarms have been situation on land but there has been a shift towards offshore installations in recent years. Offshore installations can be anchored to the seabed or attached to moorings and floating structures. As of 2019, there were over 5 047 grid-connected wind turbines across 110 farms in 12 countries (Wind Europe, 2020). Offshore wind is a relatively new sector for Norway. According to Wind Europe, Norway has a single turbine connected to the grid, with a capacity of 2.3 MW, but it is currently not operational (Wind Europe, 2020). A floating windfarm, Hywind Tampen, with a capacity of 88 MW across 11 turbines, is coming online in the next three years (Wind Europe, 2020).

The average capacity of turbines and size of offshore wind farms has been increasing since they first become commercially operational in 2002 (Bailey et al., 2014). The size of wind turbines has been growing, including that of the rotary blades to broaden the sweep areas and capture more energy. The increasing length of turbine blades has prompted the more widespread use of advance composite and thermoplastic materials. The materials used need to be of high performance, be highly mechanically and UV resistant[16]. According to the European Wind Energy Association, between 110 and 140 kilotons of composites were consumed by the wind turbine industry for manufacturing blades in 2010.

Plastics are used across the whole structure of a wind turbine, from the rotor blades (including blade tips, connections), the generation, pitch drive and yaw drive, as well as the tower (cable fixings), insulation in the transformer and corrosion protection. Most blades are generally fiberglass, formed from epoxy resin systems to infuse fibres. Concerns have been raised as to the generation of microplastics from offshore windfarm installations which could be caused by the shedding of active turbines, or though installation and decommissioning. The routine maintenance, accidental damage and blade upgrading are the three major waste sources in the operation and maintenance stage for wind turbine blades (Liu and Barlow, 2017).

[16] https://f.nordiskemedier.dk/2z0acafd4coa6z1a.pdf

*Identification of industries that can be linked to microplastic release:* Offshore wind

*Discharge from product lifecycle*: Installation, use and decommissioning. Routine maintenance, minor and major repairs.

*Quantity calculation given by weight and number of particles:*

**There is currently no data available to estimate the amount of plastics and microplastics entering the Norwegian coastal environment from wind farms.**

In a study looking into the repairs carried out on blades, Liu and Barlow (2017) said that 15 kg fibre, resin and coating paint is enough for minor repairs per wind turbine blade with a maximum material consumption of 75 kg. Scaling to major repairs this could be up to 150 kg. It is not possible to take these values and estimate the numbers of microplastic fibres released to the environment during use or maintenance.

*Microplastic polymer composition:* Epoxy resin fibres and thermoset composites. Composites account for more than 90% of the weight of WT blades. High-grade epoxy and polyester are the mainstream resins used (Liu and Barlow, 2017).

*Microplastic size range:* There have been no studies specifically addressing the size of items spilled into the Norwegian marine environment.

*Associated additives:* it was not possible to find a list of additives associated with the plastic components of wind turbines

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports***
There is currently no data available to estimate the amount of plastics and microplastics entering the Norwegian coastal environment from wind farms (**Table 33**). Only speculation for the generation of microplastics exists. **Therefore, the data quality assessment score applied to plastic production is: 20**

**Table 33.** Data Quality and Assessment Score for vessel maintenance.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |
| **Geographical** | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |

*Missing data required to provide greater certainty in values:* The generation of microplastics from all aspects of a wind turbine should be considered. This should then be compared to data of environmental levels of plastics that can be linked to the source.

Summaries of literature confirming the presence of microplastics related to source: None.

## 7.9 Land-based industry and other activities

*Description:* Many industries are located on the shorelines of the Norwegian marine environment. Their proximity to the ocean provides easy transport of products and interaction with the maritime industry. Industries include production facilities for plastics, paints and other materials. There are about 1 500 industries that operate on land, with roughly 600 reporting their annual discharges to Norsk Utslipp. Industry and other land-based activities that may have discharges of plastics and microplastics into the marine environment are listed in **Table 34**. Further releases could be related to inadvertent release or spills during production. There are currently no requirements for industries to report spills of plastics, only waste products. This report will not go into details of land-based industries as they are included in a parallel report (Sundt et al., 2021). Land-based aquaculture industry is discussed within Section 7.6.

As there are many different industries, including paint and plastic production, the distances that microplastics move from sources could vary. In reference to paint particles, the distance how far particles travel will probably be small as their high specific gravity will facilitate the rapid sinking to sediments in the vicinity of the source. Whereas, less dense materials, such as EPS will float. Both raw plastic pellets and EPS have been identified on shorelines. The example of plastic production is used herein.

*Period in life cycle that discharge occurs:* Production and handling. For example, plastic production pellets may be lost at any point in the plastic value chain, cat compounders, master batch makers, distributors, resellers, storage locations, processors, recyclers, waste management, ports and transport (already discussed in Section 7.2.1.1).

*Identification of industries or sectors that can be linked to release:* **Table 34**

**Table 34.** Land-based industries with possible direct discharges to the marine environment (located by the coast) which may be a source of microplastics. Data obtained from Norsk Utslipp, November 2020.

| | Registered companies | Companies with possible discharges to the marine environment |
|---|---|---|
| Food processing | 191 | 69% |
| Fish – processing, net washery, impregnation, coatings | 100 | 97% |
| Mineral industry (exception gravel) | 88 | 92% |
| Airports (commercial and military) | 55 | 87% |
| Chemical industry | 55 | 85% |
| Metallurgy industries | 48 | 88% |
| Hospitals | 39 | 79% |
| Feed production | 35 | 94% |
| Hazardous waste sites, treatment | 35 | 89% |
| Waste incineration | 28 | 68% |
| Wood treatment, paper, cellulose | 28 | 57% |
| Asphalt production | 26 | 65% |
| Chemical/electrolytical surface treatment | 22 | 73% |
| EE waste – recycling | 20 | 75% |
| Mechanical surface treatment incl. shipyards, dry docks, steel | 17 | 94% |
| Plastic production (and fiberglass) incl EPS, PUR, Composites | 16 | 81% |
| Motor sports | 14 | 50% |
| Laundries | 11 | 91% |
| Oil and gas onshore | 9 | 100% |
| Textiles, leather, ropes | 9 | 78% |
| Ship recycling, demolition | 6 | 100% |

*Quantity calculation of source:* There is currently no data available to estimate the amount of plastics entering the Norwegian environment from production facilitates both through operational discharges and accidental spills. Similarly, there are no values on the loss of macroplastics associated with production facilities to interpret the generation of secondary microplastics. In an earlier report, Sundt et al., 2014 estimated that around 10 000 tonnes of raw plastic materials were produced in Norway annually, with some exported, as well as imported. The report suggested that the emission factor (0.4 g per kg produced) from Norwegian plastic producers and recyclers was insignificant, yet still possible. These values do not include specifics to the marine environment. In their recent report, Sundt et al. (2021) identified that 10 – 50 tonnes of pellets could be released directly into the ocean (but there was no distinction between transport and production spills).

**There is currently no data available to estimate the amount of plastics and microplastics entering the Norwegian coastal environment from producers or converters.**

*Polymer composition:* This will be dependent on the industry. Some of the most common plastics imported and exported in Norway and PE, PP, PS and acrylic. One can assume that the list of plastic polymers derived from plastic production and paint would be as diverse and complex, therefore an exhaustive list is not included here. Similarly, industries with grey water discharges to the marine environment would include the washing of textiles which contain a range of different polymers.

*Microplastic size range:* Plastic raw materials are made in different size ranges, taking pellets as an example, they are generally 1 – 5 mm (Sundt et al., 2014).

Microplastics which are added to paint have been reported to cross a large size spectrum from few to hundreds of microns (Lassen et al., 2016). One could expect that if paint particles are lost from production facilities they could be within this size category. There have been no studies specifically addressing the size of paint particles identified close to production facilities. However, Haave et al. (2019) identified PUR particles in the size range 11 – 300 µm in sediments from Bergen Fjord.

*Associated additives:* One can assume that the list of plastic associated additives in coastal production facilities would be as diverse as the list of polymers, therefore an exhaustive list is not included here.

*Description of the uncertainty:* ***Data source: Tier 1 – publications and reports, Tier 2 – databases***
There is no information on the volume of paint spilled during production in Norway or the volume of materials spilt from other production facilitates (**Table 35**). No calculation can be made related to the volumes entering the marine environment. **Therefore, the data quality assessment score applied to microplastics derived from coastal industries is: 12**

**Table 35.** Data Quality and Assessment Score for microplastics derived from land-based industry.

| Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Reliability** | Verified by measurements | Verified data, partially based on assumptions | Non-verified data, based on estimates | Qualified estimate (by expert) | Non-qualified estimate |
| **Completeness** | Representative data | Some | Limited | Few | Unknown |
| **Temporal** | <3 years old | <6 years old | <10 years old | <15 years old | Unknown |

| Geographical | Norwegian | Nordic | European | Similar geographical conditions | Unknown or vastly different |
|---|---|---|---|---|---|

*Description missing data required to provide greater certainty in values:* Currently there is no quantitative data available on the generation and release of microplastics from land-based industries with discharges directly to the sea. Some companies may have initiated site-specific investigations of unintentional discharges from their production sites, this kind of data is not yet requested from Norwegian authorities and thus probably kept confidential. To build an evidence base it will be necessary to:

- Perform an inventory of the number of industries (incl. production facilities) with discharges directly to the Norwegian marine environment.
- The locations of the discharge points should be identified, and monitoring conducted to formulate emissions and calculation of the volumes of product released annually compared to the tonnes they produce, as well as import and export.

Summaries of literature confirming the presence of microplastics related to source: There have been no studies specifically addressing the size of items discharged to the Norwegian marine environment. In regard to plastic production, pellets are regularly found on shorelines (e.g., Bråte et al., 2019) and pellets have been observed outside plastic plants in the Nordic countries (Karlsson et al., 2018). A study from the UK found the pre-production pellet loss to the environment from production facilities is likely to be at least 105 tonnes, and possibly as high as 1,054 tonnes each year. These tonnages equate to 5 billion and 53 billion pellets per annum respectively (Cole and Sherrington, 2016).

Other industries should also be investigated, for example, microplastic pollution has been found in the sediment and water in the vicinity to a textile industrial area in China (Deng et al., 2020). Samples were dominated by polyester fibres, and the authors highlighted that the spatial distributions varied between the different factories and market areas.

# 8 Appendix tables

**Table 36.** List of common plastic additives and their associated functions and potential effects.

| ***Substance group*** | **Substances** | **Category / Type of Additive** | **Associated Plastics** | **Comments** | **Effects** | **Norwegian priority list (NPL) of chemicals** |
|---|---|---|---|---|---|---|
| **Adipates** | *di-(2-butoxyethyl) adipate (DBEA), di-(2-ethylhexyl) adipate (DEHA), di-heptyl adipate (DHA), di-methyl adipate (DMA), di-octyl adipate (DOA), heptyl adipate (HAD), heptyl octyl adipate (HOA)* | Plasticisers | PVC | Used in coatings, adhesives, sealants, polishes and waxes. | EDC | Yes |
| **Borates** | Boric acid | Flame retardants | Non-woven polymers, PS beads | Primary industrial use is the manufacture of textile fiberglass used to reinforce plastics. | EDC | Candidate list |
| | Disodium tetraborate (Borax) | Buffering agent | Resins and nylon | - | - | Candidate list |
| **Brominated Flame Retardants (BFR)** | *Hexabromocyclododecane (HBCD)*<br>- α, β and γ forms | Flame Retardants | PS, EPS, XPS, HIPS, PE, PP, PUR | - | EDC | Yes |
| | *Polybrominated diphenyl ethers (penta, octa & deca forms) (PBDEs)* | Flame Retardants | ABS, PS, phenolic resin | Most common BFR (60% of world market), also commonly identified in the environment | - | Yes |
| | Tetrabromobisphenol A *(TBBPA)* | Flame Retardants | PC, epoxy resins | One of the most common flame retardants | - | Yes |
| | *Decabromodiphenylethane (DBDPE)* | Flame Retardants | - | Used for many applications including electrical equipment, adhesives and sealants | EDC | Yes |
| **Aromatic compounds** | Benzotriazols *(UV 320, UV 326, UV 327, and UV 328)* | UV Stabilisers | - | - | - | vPBT, PBT |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Chlorinated aromatic compounds** | Triclosan | Biocide | PE, PP, PVC, polyesters, PA fibres | - | EDC | Yes |
| **Carboxylic acids** | Acetyl tributyl citrate (ATBC) | Plasticisers | PVC films | - | - | - |
| | Perfluorooctanoic acid (PFOA) | Dispersing agent, Antistatic, surfactant | PTFE, PVDF, FEP | - | - | Yes |
| **Fluorinated gases** | Hydrofluorocarbons (HFCs)<br>Perfluorocarbons (PFCs)<br>Sulphur hexafluoride ($SF_6$) | Foaming agent | XPS, PUR | Used as a blowing agent in insulating plastic products | - | Yes |
| **Inorganic compounds** | Calcium carbonate | Filler | | - | - | - |
| | Hydrazine | Polymerisation | PUR | - | - | Candidate list |
| | Potassium hydroxyoctaoxodizincatedichromate | Corrosion inhibition | Epoxy, PUR, alkyd, polyester, acrylic resins, | Inhibits corrosion | Carcinogenic | Candidate list and NPL |
| **Metals/ Metalloids** | Arsenic Compounds: *10,10'-oxybisphenoxarsine (OBPA)* | Antimicrobial | PVC, PUR, LDPE | Accounts for 70% demand for antimicrobials in plastics | - | Yes |
| | Cadmium compounds | Stabilisers (heat and UV), pigments | PVC, other plastics with colour | Banned in the EU | - | Yes |
| | Chromium compounds: Chromium trioxide | Pigments | PVC, PE, PP | Also used as a catalyst for plastic production | - | Candidate list and NPL |
| | Cobalt (II) diacate | Pigment | PET | Also used as a catalyst in the production of purified terephthalate acid- an intermediate for the manufacture of polyester fibre | - | Candidate list |
| | Lead compounds: Lead chromate, lead chromate molybdate sulphate red, lead sulfochromate yellow | Stabilisers (heat and UV), pigments | PVC, HDPE, LDPE, PP | Many | - | Candidate list and NPL |
| | Mercury compounds | Catalyst | PUR | - | - | Yes |
| **Organometallic compounds** | Copper pyrithione, Copper thiocyanate | Biocide | - | High toxicity similar to TBT | Enzyme inhibition | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Tributyl tin/ triphenyl tin<br>*Bis(tributyltin)oxide (TBTO)* | Biocide: Antimicrobial / Antifoulant | PUR, PVC | Substance is banned in the EU | EDC | Yes |
| | Zinc pyrithione, Zineb, Ziram | Antimicrobial / Antifoulant | - | - | EDC | - |
| **Paraffins** | Short-chained chlorinated paraffins (SCCP)<br>Medium-chained chlorinated paraffins (MCCP)<br>Long-chained chlorinated paraffins (LCCP) | Plasticiser,<br>Flame retardants | PE, PP, PVC, PUR, modified cellulose | Used in wires and caballing, flexible films, paints, adhesives, food packaging, sealants and rubbers. | PBT, vPvB | Candidate list and NPL |
| **Parabens** | *Methyl 4-hydroxybenzoate, Ethyl 4-hydroxybenzoate, propyl 4-hydroxybenzoate,* | Biocide | Rubber products incl. SBR | - | EDC | - |
| **Phenols** | Bisphenol A (BPA) | Antioxidant<br><br>Monomer | PP, PE, PVC<br><br>PC, epoxy resins, PUR | Oestrogen mimic, many replacements have been introduced. | EDC | Yes |
| | Bisphenol S (BPS) | Antioxidant, curing agent | epoxy resins | - | EDC | No |
| | Bisphenol F (BPF) | Antioxidant | epoxy resins | - | EDC | No |
| | Nonylphenol | Monomer, Catalyst, Heat stabiliser | epoxy resins | - | EDC | Yes |
| | Octylphenol, *octylphenol ethoxylate, 4-tert-Octylphenol 4-(1,1,3,3-tetramethylbutyl) phenol* | Monomer, Heat stabiliser, Emulsifier | PVC, PP and PS,<br><br>PTFE, SB-copolymers, Phenol resins | - | EDC | Candidate list and NPL |
| | Hindered phenol *Butylated hydroxytoluene (BHT), Butylated hydroxyanisole (BHA)* | Stabiliser | - | - | EDC | - |
| **Phthalates / Phthalate esters (PAE)** | *Benzyl butyl phthalate (BBP)* | Plasticiser | PVC, PVA, PMMA, polyesters | BBP is typically used together with older phthalates | EDC | Candidate list |
| | *Dibutyl phthalate (DBP)* | Plasticiser | PET, PVC, PVA | Anti-cracking agents (used in nail varnish), also now | EDC | Candidate list |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | used as PVA based adhesives | | |
| | *Dicyclohexyl phthalate (DCHP)* | Plasticiser | PVC | - | EDC | - |
| | *Di-(2-ethylhexyl) phthalate (DEHP)* | Plasticiser | PVC, PMMA, ABS, PS, polyester | Dominant plasticiser (37.1% of global production)[17] and used for flexible plastics for industrial and commercial use. Use and consumption decreased from 2000s. | EDC | Candidate list and NPL |
| | *Diethyl phthalate (DEP), di(hexyl, octyl, isodecyl) phthalate* | Plasticiser | PET | Skin softeners, colours, fragrance fixers | EDC | - |
| | *di(heptyl, nonyl, undecyl) phthalate (DHNUP)* | Plasticisers | PVC | - | EDC | Candidate list |
| | *Diisobuty lphthalate (DiBP)* | Plasticiser | PVC, PS, | Specialist plasticizers used in products. | EDC | Candidate list |
| | *Diisoheptyl phthalate (DIHP)* | Plasticiser | PVC, PUR acrylics | PVC and sealants | EDC | Candidate list |
| | *Diisononyl phthalate (DINP)* | Plasticisers | PVC | - | EDC | - |
| | *Di-2(methoxyethyl) phthalate (DMEP)* | Plasticiser | Nitrocellulose, acetyl cellulose, PVA, PVC, | - | EDC | Candidate list |
| | *Dipentyl phthalate (DPP)* | Plasticisers | PVC | - | EDC | - |
| **Phosphates (organophosphates)** | *Tris(2-chloroethyl) phosphate (TCEP)* | Plasticisers, flame retardant | PVC, PUR, polyester, PA, PC, PMMA | The main use of today is in the production of unsaturated polyester resins (80%) | - | Candidate list and NPL |
| | *Tris(2-chlor-1-methylethyl) phosphate (TCPP)* | Flame retardant | PUR | - | - | - |
| | *Tris-nonyl-phenyl phosphate (TNPP)* | Stabiliser | - | - | EDC | - |
| **Other organic compounds** | (Poly)acrylamides | Flocculant, Antioxidant and UV stabilisers | PMMA | Residual monomer is not chemically bound to the polymer and can migrate | - | Acrylamide on Candidate list |
| | Polyaromatic hydrocarbons (PAHs) | Plasticisers | ABS, PP | Impurity in plasticisers | - | - |
| | Polychlorinated biphenyls (PCBs) | Plasticisers | - | | EDC | |

[17] ECPI, 2016

| | | | | | | |
|---|---|---|---|---|---|---|
| | Amine ethoxylates | Antistatic | - | Oil and gas, textiles and agrochemicals | - | - |
| | Anilines: *2,2'-dichloro-4,4'methylenedianiline (MOCA)* | Curing agent | PMMA, PUR, resins | - | - | Candidate list |
| | Benzophenones | Stabiliser | - | - | EDC | - |
| | *Chloromethane, methyl chloride* | Foaming agent | PS-, PE-, PP, PUR-, Phenol resin-, acetylcellulose-foams | Used as a blowing agent in foams | - | - |
| | Carbamate /dithiocarboamate | Antioxidant, accelerator | - | - | EDC | - |
| | Fatty acids: Amides and esters, stearates, waxes<br><br>*Diazene-1,2-dicarboxamide (ADCA)* | Slip agents, Anti-static<br>Blowing agent | Waxes<br><br>PVC, PE, epoxy resins | - | - | - |
| | Formaldehyde, oligomeric | - | Epoxy resins and high-performance polymers | - | - | Candidate list |
| | Ammonium compounds | Anti-static | - | - | - | - |
| | Trichloroethylene | Intermediate | PVC | - | - | Candidate list and NPL |
| | 4,4'-diaminodiphenylmethane (MDA) | Precursor | PUR, polyether ether ketone | - | - | Candidate list |
| | 2-Methoxyethanol | Solvent | Epoxy resins and PVA | - | - | Candidate list |
| **Other additives in antifouling paints** | Capasicin, Chlorothalonil, Dichlofluanid, Diuron, Folpet, Irgarol 1051 (Cybutryne), Maneb, Medetomidine, DCOIT (sea-Nine 211), TCMS pyridine (Densil 100), TCMTB (Busan), Thiram, Tolylfluanid, TPBP (KH101), Trapyril (Econea), Irgarol 1051 | Biocides | Antifouling paints | More information in Brooks et al., Guardiola et al. 2012 | Mortality, Toxicity (embyo, immune) EDC | - |

**Table 37**. Import of raw plastic material into Norway. Data obtained from SSB October 2020. Search terms were amount in kg (M1), year 2019, varenummer 39-43 (only the term *ubearbeidd* plastics included, meaning unprocessed plastics), import and all countries were added. Rubbers and silicones were excluded, as well as other obvious non-plastic items. https://www.ssb.no/statbank/table/08801/chartViewLine/.

| Material | 2019 |
|---|---|
| | Amount (kg) |
| **Total** | **287489952** |
| Polyethylen, ubearbeidd, spesifikk vekt min 0,94 g/kbcm, uten innh av fluorkarbonene HFK, PFK eller KFK | 79690731 |
| Polystyren, ubearbeidd, ekspanderbar | 47800927 |
| Akrylpolymerer, ubearbeidd, unnt polymetylmetakrylat | 44613328 |
| Kopolymerer av propylen, ubearbeidd | 19447424 |
| Polyethylen, ubearbeidd, spesifikk vekt u 0,94 g/kbcm, uten innh av fluorkarbonene HFK, PFK eller KFK | 12138249 |
| Polypropylen, ubearbeidd, uten innh av fluorkarbonene HFK, PFK eller KFK | 10371317 |
| Polystyren, ubearbeidd, ikke ekspanderbar, uten innh av fluorkarbonene HFK, PFK eller KFK | 8447776 |
| Polyvinylklorid, ubearbeidd, ikke blandet med andre stoffer | 8314325 |
| Polyeter, unnt polyacetaler, ubearbeidd, uten innh av fluorkarbonene HFK, PFK eller KFK | 7863498 |
| Polyuretaner, ubearbeidd, uten innh av fluorkarbonene HFK, PFK eller KFK | 6091675 |
| Polyestere, umettede, unnt alkyder, ubearbeidd | 5295584 |
| Epoksyharpikser, ubearbeidd | 4372967 |
| Fenolharpiks, ubearbeidd, uten innh av fluorkarbonene HFK, PFK eller KFK | 3730191 |
| Kopolymerer av ethylen-alfa-olefin med spesifikk vekt under 0,94, ubearbeidd | 3385724 |
| Kopolymerer i vinacetal i vandig dispersjon, ubearbeidd | 3288779 |
| Alkydharpikser, ubearbeidd | 2917882 |
| Polymerer av styren, ubearbeidd, unnt polystyren, kopolymerer av styren-akrylnitril (SAN) og akrylnitril-butadienstyren ABS | 2749629 |
| Polyvinylklorid, ubearbeidd, blandet med andre stoffer, mykgjort | 2473149 |
| Polyamider, ubearbeidd, unnt polyamid -6, -11, -12, -6,6, -6,9 -6,10 el -6,12 | 2008229 |
| Polyamider -6, -11, -12, -6,6, -6,9, -6,10 el -6,12, ubearbeidd | 1908901 |
| Kopolymerer av vinylacetat i ikke-vandig dispersjon, ubearbeidd | 1871858 |
| Polyvinylacetat, i vandig dispersjon, ubearbeidd | 1590401 |
| Polymerer av ethylen, ubearbeidd, unnt polyethylen, kopolymerer av ethylen-vinylacetat og kopolymerer av ethylen-alfa-olefin med spesifikk vekt under 0,94 | 1556526 |

| | |
|---|---|
| Polykarbonater, ubearbeidd | 801931 |
| Poly(etylentereftalat) med en viskositetsindeks på 78 ml/g eller mer, ubearbeidd | 700088 |
| Kopolymerer av ethylen-vinylacetat, ubearbeidd | 651572 |
| Polymere av propylen eller andre olefiner, ubearbeidd, unnt kopolymerer av propylen, polyisobutylen og polypropylen | 492870 |
| Kopolymerer av akrylnitril-butadienstyren (ABS), ubearbeidd | 430038 |
| Kopolymerer, ubearbeidd, unnt av vinylacetat | 429744 |
| Ureaharpiks: tioureaharpiks, ubearbeidd | 390615 |
| Polyacetaler, ubearbeidd | 374022 |
| Poly(etylentereftalat) med en viskositetsindeks på under 78 ml/g, ubearbeidd | 317007 |
| Polyvinylklorid, ubearbeidd, blandet med andre stoffer, ikke mykgjort | 230541 |
| Aminoharpiks, ubearbeidd, unnt ureaharpiks, tioureaharpiks, melaminharpiks og poly(metylenfenylisocyanat) (rå MDI, MDI-polymer) | 185095 |
| Polymerer av vinylestere, ubearbeidd, unnt polymerer av vinylacetat og av vinylalkoholer | 110461 |
| Melaminharpiks, ubearbeidd | 89982 |
| Kopolymerer av styren og acrylonitril (SAN), ubearbeidd | 87464 |
| Polyvinylacetat, i ikke-vandig dispersjon, ubearbeidd | 73418 |
| Polymerer av vinylidenklorid, ubearbeidd | 57856 |
| Polyisobutylen, ubearbeidd | 28596 |
| Polymetylmetakrylat, ubearbeidd | 27022 |
| Kopolymerer av vinylklorid, ubearbeidd, unnt med vinylacetat | 22137 |
| Poly(melkesyre), ubearbeidd | 21044 |
| Fluorholdige polymerer, ubearbeidd, unnt polytetrafluoretylen | 20981 |
| Polymerer av vinylklorid o a olefiner, ubearbeidd, unnt PVC, kopolymerer, fluorholdige polymerer, vinylidenkloridpolymerer | 7897 |
| Kopolymerer av vinylklorid-vinylacetat, ubearbeidd | 6024 |
| Polytetrafluoretylen, ubearbeidd | 3477 |
| Polyeter, unnt polyacetaler, ubearbeidd, med innh av fluorkarbonene HFK, PFK eller KFK | 1000 |

**Table 38**. Export of raw plastic material into Norway. Data obtained from SSB October 2020. Search terms were amount in kg (M1), year 2019, varenummer 39-43 (only the term *ubearbeidd* plastics included, meaning unprocessed plastics), import and all countries were added. Rubbers and silicones were excluded, as well as other obvious non-plastic items. https://www.ssb.no/statbank/table/08801/chartViewLine/.

| Material | 2019 |
|---|---|
| | **Amount (kg)** |
| **Total** | **10073136** |
| Akrylpolymerer, ubearbeidd, unnt polymetylmetakrylat | 3703995 |
| Kopolymerer av propylen, ubearbeidd | 2409656 |
| Alkydharpikser, ubearbeidd | 1245743 |
| Epoksyharpikser, ubearbeidd | 531452 |
| Polyamider, ubearbeidd, unnt polyamid -6, -11, -12, -6,6, -6,9 -6,10 el -6,12 | 525540 |
| Polyuretaner, ubearbeidd, uten innh av fluorkarbonene HFK, PFK eller KFK | 438811 |
| Polymerer av ethylen, ubearbeidd, unnt polyethylen, kopolymerer av ethylen-vinylacetat og kopolymerer av ethylen-alfa-olefin med spesifikk vekt under 0,94 | 295637 |
| Polymetylmetakrylat, ubearbeidd | 171158 |
| Polymerer av styren, ubearbeidd, unnt polystyren, kopolymerer av styren-akrylnitril (SAN) og akrylnitril-butadienstyren ABS | 148035 |
| Polyeter, unnt polyacetaler, ubearbeidd, uten innh av fluorkarbonene HFK, PFK eller KFK | 109912 |
| Kopolymerer, ubearbeidd, unnt av vinylacetat | 103860 |
| Polymere av propylen eller andre olefiner, ubearbeidd, unnt kopolymerer av propylen, polyisobutylen og polypropylen | 64654 |
| Polyacetaler, ubearbeidd | 59088 |
| Polysulfider, polysulfoner o.l., fremstillet ved kjemisk syntese, unnt harpikser samt polyterpener, ubearbeidd | 58544 |
| Polyamider -6, -11, -12, -6,6, -6,9, -6,10 el -6,12, ubearbeidd | 56969 |
| Polyuretaner, ubearbeidd, med innh av fluorkarbonene HFK, PFK eller KFK | 52831 |
| Kopolymerer av ethylen-vinylacetat, ubearbeidd | 36911 |
| Polyvinylacetat, i ikke-vandig dispersjon, ubearbeidd | 24501 |
| Polykarbonater, ubearbeidd | 22321 |
| Polymerer av vinylidenklorid, ubearbeidd | 6795 |
| Polymerer av vinylestere, ubearbeidd, unnt polymerer av vinylacetat og av vinylalkoholer | 2210 |
| Polyvinylalkoholer, også med innhold av ikke-hydrolyserte acetatgrupper, ubearbeidd | 1000 |
| Petroleum-, kumaron-, inden- og kumaron-indenharpikser, samt polyterpener, ubearbeidd | 889 |
| Polyestere, mettede, unnt alkyder, ubearbeidd, med innh av fluorkarbonene HFK, PFK eller KFK | 676 |

| | |
|---|---|
| Polytetrafluoretylen, ubearbeidd | 510 |
| Poly(melkesyre), ubearbeidd | 347 |
| Kondensasjons,- polykondensasjons-, og polyaddisjonsprodukter, ubearbeidd | 283 |
| Halogenert isobuten-isoprengummi (CIIR el BIIR), ubearbeidd el som plater, duk el bånd | 259 |
| Polymerer av vinylklorid o a olefiner, ubearbeidd, unnt PVC, kopolymerer, fluorholdige polymerer, vinylidenkloridpolymerer | 239 |
| Kopolymerer av vinylklorid-vinylacetat, ubearbeidd | 202 |
| Polyethylen, ubearbeidd, spesifikk vekt u 0,94 g/kbcm, med innh av fluorkarbonene HFK, PFK eller KFK | 54 |
| Fluorholdige polymerer, ubearbeidd, unnt polytetrafluoretylen | 54 |

**Table 39.** Plastic use in aquaculture systems (modified from Huntington 2019).

| | Floating open-water cages | | | | | | | Suspended ropes / longlines | | | | Coastal and inland ponds | | | | | Tanks (inc. RAS) | | | Characteristics | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Material | Collars (inc. handrails) | Collar floatation | Buoys | Ropes | Net enclosures | Predator and other nets | Feeding systems (pipes and hoppers) | Buoys | Ropes | Floatation raft | Stock containment | Pond liners | Sampling/harvest nets | Plastic housing | Aerators/pumps | Feeding systems | Spawning, incubation and stock holding tnks | Pipework (inc. Connectors, valves) | Office/laboratory fixtures | In use/recyclability | When lost |
| Acrylic (PMMA) | | | | | | | | | | | | | | | | | | | ✓ | Lightweight, recyclable | Slow level of abrasion |
| Expanded Polystyrene (EPS) | | ✓ | | | | | | | | ✓ | | | | | | | | | ✓ | Lightweight, recyclable | Buoyant and easily abraded |
| Fibre-reinforced plastics (FRP) | | | | | | | ✓ | | | | | | | | | ✓ | ✓ | ✓ | | Difficult to recycle | Will splitter with time |
| High-density polyethylene | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | Tough, recycled | Will fragment and abrade |
| Linear low-density polyethylene (LLDPE) | | | | | | | | | | | | ✓ | | | | | | | | Flexible and strong | Will fragment and abrade |
| Low density polyethylene (PE) | | | ✓ | | | | | ✓ | | | | ✓ | | ✓ | | | | | ✓ | Flexible, recycled | Will fragment and abrade |
| Nylon (Polyamide, PA) | | | | ✓ | ✓ | ✓ | | | ✓ | | ✓ | | ✓ | | | | | | ✓ | Elastic, abrasion resistant | Will fragment and abrade |
| Polyethylene (PE) | | | ✓ | | | ✓ | | ✓ | | | | | | | | | | | | Cheap | Will fragment and abrade |
| Polyethylene terephthalate (PET) | | | | ✓ | | | | | ✓ | | | | | | | | | | | Strong, recycled | Will fragment and abrade |
| Polypropylene (PP) | | | | ✓ | ✓ | | | | ✓ | | ✓ | | ✓ | | | | | | | Buoyant, recycled | Will fragment and abrade |
| Polyvinyl chloride (PVC) | ✓ | | | | | | ✓ | | | | | | | | ✓ | ✓ | | ✓ | ✓ | Tough, rarely recycled | Will fragment and abrade |
| Ultra-high molecular weight Polyethylene (UGHMw-PE) | | | | | ✓ | | | | | | ✓ | | ✓ | | | | | | | Expensive, light and strong | Unknown but stronger than most materials |

# 9 References

Almroth, B.M.C., Åström, L., Roslund, S., Petersson, H., Johansson, M. and Persson, N.K., 2018. Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment. Environmental Science and Pollution Research, 25(2), pp.1191-1199.

Amec Foster Wheeler Environment & Infrastructure UK Limited, 2017. Intentionally added microplastics in products. Final Report for European Commissions (DG Environment). 220 pp.

Andrady, A.L. and Rajapakse, N., 2016. Additives and chemicals in plastics. In Hazardous Chemicals Associated with Plastics in the Marine Environment (pp. 1-17). Springer, Cham.

Arp et al., 2018. Microplastics in sediment on the Norwegian Continental shelf. Report for the Norwegian Environmental agency 2018-0050.

Avio, C.G., Cardelli, L.R., Gorbi, S., Pellegrini, D. and Regoli, F., 2017. Microplastics pollution after the removal of the Costa Concordia wreck: First evidences from a biomonitoring case study. Environmental Pollution, 227, pp.207-214.

Bailey, H., Brookes, K.L. and Thompson, P.M., 2014. Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquatic biosystems, 10(1), pp.1-13.

Booth, A.M., Kubowicz, S., Beegle-Krause, C., Skancke, J., Nordam, T., Landsem, E., Throne-Holst, M. and Jahren, S., 2017. Microplastic in global and Norwegian marine environments: Distributions, degradation mechanisms and transport. Miljødirektoratet M-918; SINTEF: Trondheim, Norway.

Boucher, J. and Friot D. (2017). Primary Microplastics in the Oceans: A Global Evaluation of Sources. Gland, Switzerland: IUCN. 43pp

Bour, A., Avio, C.G., Gorbi, S., Regoli, F. and Hylland, K., 2018. Presence of microplastics in benthic and epibenthic organisms: influence of habitat, feeding mode and trophic level. Environmental Pollution, 243, pp.1217-1225.

Brooks, S. J., Harman, C., Grung, M., Farmen, E., Ruus, A., Vingen, S., Godal, B.F., Baršienė, J., Andreikėnaitė, L., Skarphéðinsdóttir, H., Liewenborg, B. and Sundt, R.C., 2011. Water column monitoring of the biological effects of produced water from the Ekofisk offshore oil installation from 2006 to 2009. Journal of Toxicology and Environmental Health, Part A, 74(7-9), pp. 582-604.

Bråte, I.L.N., Eidsvoll, D.P., Steindal, C.C. and Thomas, K.V., 2016. Plastic ingestion by Atlantic cod (*Gadus morhua*) from the Norwegian coast. Marine Pollution Bulletin, 112(1-2), pp.105-110.

Bråte, I.L.N., Huwer, B., Thomas, K.V., Eidsvoll, D.P., Halsband, C., Almroth, B.C. and Lusher, A., 2017. Micro-and macro-plastics in marine species from Nordic waters. Report for Nordic Council of Ministers. 103p.

Bråte, I.L.N., Hurley, R., Iversen, K., Beyer, J., Thomas, K.V., Steindal, C.C., Green, N.W., Olsen, M. and Lusher, A., 2018a. Mytilus spp. as sentinels for monitoring microplastic pollution in Norwegian coastal waters: A qualitative and quantitative study. Environmental Pollution, 243, pp.383-393.

Bråte, I.L.N., Blázquez, M., Brooks, S.J. and Thomas, K.V., 2018b. Weathering impacts the uptake of polyethylene microparticles from toothpaste in Mediterranean mussels (*M. galloprovincialis*). Science of the Total Environment, 626, pp.1310-1318.

Bråte, I.L.N., Hansen, L.M., Eidsvoll, D., Moe, N. and Buenaventura, N.T., 2019. OSPAR-metodikk og plastanalyse av strandsøppel fra Nordre Langåra og Akerøya. NIVA report 7440-2019. 32p.

Bråte, I.L.N., Hurley, R., Lusher, A., Buenaventura, N., Hultman, M., Halsband, C. and Green, N., 2020. Microplastics in marine bivalves from the Nordic environment. Report for Nordic Council of Ministers. 128p.

Butt, N., 2007. The impact of cruise ship generated waste on home ports and ports of call: A study of Southampton. Marine Policy, 31(5), pp.591-598.

Cesa, F.S., Turra, A. and Baruque-Ramos, J., 2017. Synthetic fibers as microplastics in the marine environment: a review from textile perspective with a focus on domestic washings. Science of The Total Environment, 598, pp.1116-1129.

Cole, G. and Sherrington, C., 2016. Study to Quantify Pellet Emissions in the UK. Eunomia, Bristol. Available at: https://www.eunomia.co.uk/reports-tools/study-to-quantify-pellet-emissions-in-the-uk/)

COWI, 2018. Miljøvennlige Småbåthavner. Report for the Norwegian Environment Agency 2017. M1048-2018. 63p.

COWI, 2019. Tiltak for å redusere utslipp av mikroplast og helse- og miljøfarlige stoffer fra marine småbåthavner. Report for the Norwegian Environment Agency 2018. M1211-2019. 77p.

Dafforn, K.A., Lewis, J.A. and Johnston, E.L., 2011. Antifouling strategies: history and regulation, ecological impacts and mitigation. Marine Pollution Bulletin, 62(3), pp.453-465.

De Falco, F., Di Pace, E., Cocca, M. and Avella, M., 2019. The contribution of washing processes of synthetic clothes to microplastic pollution. Scientific Reports, 9(1), pp.1-11.

Demirel, Y.K., 2018. New horizons in marine coatings. GMO Journal of Ship and Marine Technology, 24(213), pp.37-53.

Deng, H., Wei, R., Luo, W., Hu, L., Li, B. and Shi, H., 2020. Microplastic pollution in water and sediment in a textile industrial area. Environmental Pollution, 258, p.113658.

Deshpande, P.C., Philis, G., Brattebø, H. and Fet, A.M., 2020. Using Material Flow Analysis (MFA) to generate the evidence on plastic waste management from commercial fishing gears in Norway. Resources, Conservation & Recycling: X, 5, p.100024.

Du, Z., Zhang, S., Zhou, Q., Yuen, K.F. and Wong, Y.D., 2018. Hazardous materials analysis and disposal procedures during ship recycling. Resources, Conservation and Recycling, 131, pp.158-171.

Earll, R.C., Williams, A.T. and Tudor, D.T., 2000. Pilot Project to establish methodologies and guidelines to identify marine litter from shipping. Report to the Maritime and Coastguard Agency. Research Project 470, Prepared by CMS.

ECHA, 2013. Annex XV restriction. Report amendment to a restriction: Substance names Cadmium and its compounds - paints, October 2013.

ECHA, 2018. Plastics additive initiative. Available at: https://echa.europa.eu/plastic-additives-initiative

ECHA, 2019. Annex XV Restriction Report - Proposal for a Restriction. Intentionally added microplastics. 22 August 2019.

Eklund, B., 2013. Disposal of plastic end-of-life-boats. Report for Nordic Council of Ministers. 75p.

Falk-Andersson, J. and Strietman, W.J. 2019. Svalbard Beach Litter Deep Dive. SALT Report 1033. 44p.

Falk-Andersson, J., Berkhout, B.W. and Abate, T.G., 2019. Citizen science for better management: Lessons learned from three Norwegian beach litter data sets. Marine Pollution Bulletin, 138, pp.364-375.

Franzellitti, S., Canesi, L., Auguste, M., Wathsala, R.H. and Fabbri, E., 2019. Microplastic exposure and effects in aquatic organisms: A physiological perspective. Environmental toxicology and pharmacology, 68, pp.37-51.

Galafassi, S., Nizzetto, L., and Volta, P., 2019. Plastic sources: A survey across scientific and grey literature for their inventory and relative contribution to microplastics pollution in natural environments, with an emphasis on surface water. Science of The Total Environment, 693, pp. 133499.

Galgani, F., Leaute, J.P., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., Goraguer, H., Latrouite, D., Andral, B., Cadiou, Y. and Mahe, J.C., 2000. Litter on the sea floor along European coasts. Marine Pollution Bulletin, 40(6), pp.516-527.

Gallo, F., Fossi, C., Weber, R., Santillo, D., Sousa, J., Ingram, I., Nadal, A. and Romano, D., 2018. Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. Environmental Sciences Europe, 30(1), p.13.

GESAMP, 2019. Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean (Kershaw P.J., Turra A. and Galgani F. editors), (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 99, 130p.

GESAMP, 2020. Sea-based sources of marine litter – a review of current knowledge and assessment of data gaps. Second Interim Report, 4th June 2020. 99, 120p.

Gilman, E., Chopin, F., Suuronen, P. and Kuemlangan, B., 2016. Abandoned, lost or otherwise discarded gillnets and trammel nets. FAO Fisheries and Aquaculture Technical Paper. No. 600. Rome, FAO

Godoy, V., Martín-Lara, M.A., Calero, M. and Blázquez, G., 2019. Physical-chemical characterization of microplastics present in some exfoliating products from Spain. Marine Pollution Bulletin, 139, pp.91-99.

Gomiero, A., Haave, M., Kögel, T., Bjorøy, Ø., Gjessing, M., Lea, T.B., Horve, E., Martins, C. and Olafsen, T., 2020. TRACKing of PLASTtic emissions from aquaculture industry (TrackPlast). NORCE Report n. 4 /2020. 70p.

Granberg, M., von Friesen, L.W., Bach, L., Collard, F., Gabrielsen, G.W. and Strand, J., 2019. Anthropogenic microlitter in wastewater and marine samples from Ny-Ålesund, Barentsburg and Signehamna, Svalbard. IVL report. C373. 28p.

Groh, K.J., Backhaus, T., Carney-Almroth, B., Geueke, B., Inostroza, P.A., Lennquist, A., Leslie, H.A., Maffini, M., Slunge, D., Trasande, L. and Warhurst, A.M., 2019. Overview of known plastic packaging-associated chemicals and their hazards. Science of The Total Environment, 651, pp.3253-3268.

Guerranti, C., Martellini, T., Perra, G., Scopetani, C. and Cincinelli, A., 2019. Microplastics in cosmetics: Environmental issues and needs for global bans. Environmental Toxicology and Pharmacology, 68, pp.75-79.

Gunaalan, K., Fabbri, E. and Capolupo, M., 2020. The hidden threat of plastic leachates: A critical review on their impacts on aquatic organisms. Water Research, 184, p.116170.

Haarr, M.K., Falk-Andersson, J-. Johnsen, H. R., Bay-Larsen, I., 2019. Marin plastforsøpling fra fiskeflåten. Repot for FHF, SALT RAPPORT NR 1039. 50pp.

Haarr, M.L., Pantalos, M., Hartviksen, M.K. and Gressetvold, M., 2020. Citizen science data indicate a reduction in beach litter in the Lofoten archipelago in the Norwegian Sea. Marine Pollution Bulletin, 153, p.111000.

Haave, M., Lorenz, C., Primpke, S. and Gerdts, G., 2019. Different stories told by small and large microplastics in sediment-first report of microplastic concentrations in an urban recipient in Norway. Marine Pollution Bulletin, 141, pp.501-513.

Hahladakis, J.N., Velis, C.A., Weber, R., Iacovidou, E. and Purnell, P., 2018. An overview of chemical additives present in plastics: migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials, 344, pp.179-199.

Hann, S., Sherrington, C., Jamieson, O., Hickman, M., Kershaw, P., Bapasola, A. and Cole, G., 2018. Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products. Report for DG Environment, European Commission. 335p.

Hansen, E., Nilsson, N.H., Lithner, D. and Lassen, C., 2013. Hazardous substances in plastic materials. Hazardous substances in plastic materials. Report for Klima- og Forurensnings- Direktoratet. 148p.

Hermabessiere, L., Dehaut, A., Paul-Pont, I., Lacroix, C., Jezequel, R., Soudant, P. and Duflos, G., 2017. Occurrence and effects of plastic additives on marine environments and organisms: a review. Chemosphere, 182, pp.781-793.

Hognes, E., Skaar, C., 2017. Avfallshåndtering fra sjøbasert havbruk. FHF rapport. OC2017-218.

Huntington, T (2019). Marine Litter and Aquaculture Gear – White Paper. Report produced by Poseidon Aquatic Resources Management Ltd for the Aquaculture Stewardship Council. 20 pp plus appendices.

Iannilli, V., Pasquali, V., Setini, A., and Corami, F., 2019. First evidence of microplastics ingestion in benthic amphipods from Svalbard. Environmental Research, 179(A), p. 108811.

IMO, 2001. International convention on the control of harmful anti-fouling systems on ships. London, International Maritime Organization, 2001.

IMO, 2019a. Hull scrapings and marine coatings as a source of microplastics. International Maritime Organization document. 33p.

IMO 2019b. End-of-Life management of fibre-reinforced plastic vessels: Alternatives to at sea disposal. Office for the London Convention/Protocol and Ocean Affairs, International Maritime Organization. 38p.

Iñiguez, M.E., Conesa, J.A. and Fullana, A., 2018. Recyclability of four types of plastics exposed to UV irradiation in a marine environment. Waste Management, 79, pp.339-345.

Jahnke, A., Arp, H.P.H., Escher, B.I., Gewert, B., Gorokhova, E., Kühnel, D., Ogonowski, M., Potthoff, A., Rummel, C., Schmitt-Jansen, M. and Toorman, E., 2017. Reducing uncertainty and confronting ignorance about the possible impacts of weathering plastic in the marine environment. Environmental Science & Technology Letters, 4(3), pp.85-90.

Jartun, M. and Pettersen, A., 2010. Contaminants in urban runoff to Norwegian fjords. Journal of Soils and Sediments, 10(2), pp.155-161.

Jartun, M., Ottesen, R.T., Steinnes, E. and Volden, T., 2009. Painted surfaces–Important sources of polychlorinated biphenyls (PCBs) contamination to the urban and marine environment. Environmental Pollution, 157(1), pp.295-302.

Jo, G.W., 2020. The need for international policy regarding lost containers at sea for reducing marine plastic litter. Journal of International Maritime Safety, Environmental Affairs, and Shipping, 4(3), pp.80-83.

Johnsen, A. and Engoy, T., 2000. Contamination from marine paints - A Norwegian perspective. Norwegian Defence Research Establishment, Kjeller, Division for Environmental Toxicology.

Kalogerakis, N., Karkanorachaki, K., Kalogerakis, G., Triantafyllidi, E.I., Gotsis, A.D., Partsinevelos, P. and Fava, F., 2017. Microplastics generation: onset of fragmentation of polyethylene films in marine environment mesocosms. Frontiers in Marine Science, 4, 84, pp. 1-15.

Karlsson, T. M., Arneborg, L., Broström, G., Almroth, B. C., Gipperth, L., & Hassellöv, M. (2018). The unaccountability case of plastic pellet pollution. Marine Pollution Bulletin, 129(1), 52-60.

Korde, J.M., Sreekumar, A.V. and Kandasubramanian, B., 2020. Corrosion inhibition of 316L-type stainless steel under marine environments using epoxy/waste plastic soot coatings. SN Applied Sciences, 2(7), 1267, pp.1-13.

Kommedal, T., 2018. Pellers på avveie. Fra Vugge til hav. Fakultet for naturvitenskap og teknologi, University of Tromso, UiT. Available at:
https://munin.uit.no/bitstream/handle/10037/14148/thesis.pdf?sequence=2&isAllowed=y

Koponen, I.K., Jensen, K.A. and Schneider, T., 2009. Sanding dust from nanoparticle-containing paints: physical characterisation. Journal of Physics: Conference Series, 151 (1), p. 012048.

Lassen, C., Hansen, S.F., Magnusson, K., Hartmann, N.B., Rehne Jensen, P., Nielsen, T.G., Brinch, A., 2015. Microplastics: Occurrence, Effects and Sources of Releases to the Environment in Denmark. Report for Danish Environmental Protection Agency. 208p.

Lindgren, J.F., Wilewska-Bien, M., Granhag, L., Andersson, K., Eriksson, K.M., 2016. Discharges to the sea. In Andersson, K et al., (Eds.) Shipping and the Environment (pp. 125-168). Springer, Berlin, Heidelberg.

Liu, P. and Barlow, C.Y., 2017. Wind turbine blade waste in 2050. Waste Management, 62, pp.229-240.

Luo, H., Xiang, Y., He, D., Li, Y., Zhao, Y., Wang, S. and Pan, X., 2019. Leaching behavior of fluorescent additives from microplastics and the toxicity of leachate to *Chlorella vulgaris*. Science of The Total Environment, 678, pp.1-9.

Lusher, A. L., Welden, N.C. 2020. Microplastic Impacts in Fisheries and Aquaculture. In: Rocha-Santos T., Costa M., Mouneyrac C. (eds) Handbook of Microplastics in the Environment. Springer, Cham

Lusher, A.L., Tirelli, V., O'Connor, I. and Officer, R., 2015. Microplastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. Scientific Reports, 5, p.14947.

Lusher A., Hollman P., Mendoza-Hill J., 2017. Microplastics in fisheries and aquaculture, FAO Fisheries and Aquaculture Technical Paper. No. 615. Rome, FAO.

Magnusson, K., Eliasson, K., Fråne, A., Haikonen, K., Hultén, J., Olshammar, M., Stadmark, J. and Voisin, A., 2016. Swedish sources and pathways for microplastics to the marine environment. A review of existing data. IVL report. C183.

Macfadyen, G., Huntington, T. and Cappell, R., 2009. Abandoned, lost or otherwise discarded fishing gear. FAO Fisheries and Aquaculture Technical Paper. No.523. Rome, FAO.

Moskeland et al., 2018. Microplastics in sediment on the Norwegian Continental shelf II: Identification through FT-IR analysis. Report for the Norwegian Environmental agency 2018. M-1231-2018.

Muller-Karanassos, C., Turner, A., Arundel, W., Vance, T., Lindeque, P.K. and Cole, M., 2019. Antifouling paint particles in intertidal estuarine sediments from southwest England and their ingestion by the harbour ragworm, *Hediste diversicolor*. Environmental Pollution, 249, pp.163-170.

Murphy, J. (Ed.,) 2001. Additives for Plastics Handbook. Elsevier. 484p.

Nashoug, B. F. 2017. "Sources of Marine Litter" – Workshop Report, Svalbard 4th - 6th September 2016. SALT Report 1017. 23p.

Nelms, S.E., Eyles, L., Godley, B.J., Richardson, P.B., Selley, H., Solandt, J.L. and Witt, M.J., 2020. Investigating the distribution and regional occurrence of anthropogenic litter in English marine protected areas using 25 years of citizen-science beach clean data. Environmental Pollution, 263(b), p.114365.

NGI 2011. Prosjekt småbåthavner - utredning av miljøfarlige utslipp som følge av drift. Kartlegging av forurensing i utvalgte småbåthavner i Norge. TA-2751/2010. 121pp.

Nordic Council of Ministers (2020). Clean Nordic Oceans main report - a network to reduce marine litter and ghost fishing. TemaNord 2020:509, 56pp.

Norén, F. and Naustvoll, L.J., 2010. Survey of microscopic anthropogenic particles in Skagerrak. Report commissioned by Klima-og Forurensningsdirektoratet. 22p.

OECD Environment Directorate, 1973. Polychlorinated Biphenyls. Their use and control. OECD Environment Directorate, Paris, France.

OECD, 2004. OECD Series on Emission Scenario Documents No. 3: Emission Scenario Document on Plastic Additives. Available at: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/mono(2004)8&docLanguage=En

OECD, 2005. Emission Scenario Document on Antifouling Products, OECD Series on Emission Scenario Documents, No. 13. Avaliable at: https://www.oecd.org/env/ehs/risk-management/47703240.pd

OECD, 2009a. Emission scenario documents on coating industry (paints, lacquers and varnishes). OECD Series on Emission Scenario Documents, No. 22, ENV/JM/MONO(2009)24. Available at: https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2009)24&doclanguage=en

OECD, 2009b. Emission Scenario Document on plastic additives, OECD Series on Emission Scenario Documents, No. 3. ENV/JM/MONO (2004)8/REV1. Available at: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2004)8/rev1&doclanguage=en

Olsen, J., Nogueira, L.A., Normann, A.K., Vangelsten, B.V. and Bay-Larsen, I., 2020. Marine litter: Institutionalization of attitudes and practices among Fishers in Northern Norway. Marine Policy, p.104211.

OSPAR, 2018. Background document on pre-production Plastic Pellets. 33p. Available at: https://www.ospar.org/documents?v=39764

Osswald, T.A., 2006. International plastics handbook: the resource for plastics engineers. Hanser Gardner Pubns.

Paetzel, M., Nes, G., Leifsen, L. and Schrader, H., 2003. Sediment pollution in the Vågen, Bergen harbour, Norway. Environmental Geology, 43(4), pp.476-483.

Peeken, I., Primpke, S., Beyer, B., Gütermann, J., Katlein, C., Krumpen, T., Bergmann, M., Hehemann, L. and Gerdts, G., 2018. Arctic sea ice is an important temporal sink and means of transport for microplastic. Nature Communications, 9(1), pp.1-12.

Piotrowska, A., Czerwińska-Ledwig, O., Serdiuk, M., Serdiuk, K. and Pilch, W., 2020. Composition of scrub-type cosmetics from the perspective of product ecology and microplastic content. Toxicology and Environmental Health Sciences, pp.1-7.

Ramirez-Llodra, E., De Mol, B., Company, J.B., Coll, M. and Sardà, F., 2013. Effects of natural and anthropogenic processes in the distribution of marine litter in the deep Mediterranean Sea. Progress in Oceanography, 118, pp.273-287.

Reddy, M.S., Basha, S., Kumar, V.S., Joshi, H.V. and Ghosh, P.K., 2003. Quantification and classification of ship scraping waste at Alang–Sosiya, India. Marine Pollution Bulletin, 46(12), pp.1609-1614.

Reddy, M.S., Basha, S., Kumar, V.S., Joshi, H.V. and Ramachandraiah, G., 2004. Distribution, enrichment and accumulation of heavy metals in coastal sediments of Alang–Sosiya ship scrapping yard, India. Marine Pollution Bulletin, 48(11-12), pp.1055-1059.

Reddy, M.S., Basha, S., Adimurthy, S. and Ramachandraiah, G., 2006. Description of the small plastics fragments in marine sediments along the Alang-Sosiya ship-breaking yard, India. Estuarine, Coastal and Shelf Science, 68(3-4), pp.656-660.

Richardson, K., Hardesty, B.D. and Wilcox, C., 2019. Estimates of fishing gear loss rates at a global scale: A literature review and meta-analysis. Fish and Fisheries, 20(6), pp.1218-1231.

Rizvi, M.J., Islam, M.R., Adekola, O. and Margaret, O.N., 2020. A sustainable shipbreaking approach for cleaner environment and better wellbeing. Journal of Cleaner Production, 270, p.122522.

Ruus, A., Green, N.W., 2002. Measure oriented environmental monitoring of the Sørfjord and Hardangerfjord 2002. Report component 2, Contaminants in organisms. Norwegian State Pollution Monitoring Programme Report no. 86502. TA-No. 19222002.

Ruus, A., Green, N.W., Maage, A. and Skei, J., 2006. PCB-containing paint and plaster caused extreme PCB-concentrations in biota from the Sørfjord (Western Norway)—A case study. Marine Pollution Bulletin, 52(1), pp.100-103.

Ruus, A., Bæk, K., Rundberget, T., Allan, I., Beylich, B., Schlabach, M., Warner, N., Borgå, K., Helberg, M. 2019. Environmental Contaminants in an Urban Fjord, 2018. Miljødirektoratet-rapport M-1441. NIVA-rapport 7410-2019.

Ryan, P.G., Dilley, B.J., Ronconi, R.A. and Connan, M., 2019. Rapid increase in Asian bottles in the South Atlantic Ocean indicates major debris inputs from ships. Proceedings of the National Academy of Sciences, 116(42), pp.20892-20897.

Sandra M., Devriese L., De Raedemaecker F., Lonneville B., Lukic I., Altvater S., Compa Ferrer M., Deudero S., Torres Hansjosten B., Alomar Mascaró C., Gin I., Vale M., Zorgno M., Mata Lara M., 2020. Knowledge wave on marine litter from aquaculture sources. Deliverable 2.2 (D2.2). Aqua-Lit project. Oostende, Belgium. 136 pp.

Schäfer, E., Scheele, U. and Papenjohann, M., 2019. Identifying Sources of Marine Litter: Application of the Matrix Scoring Technique to the German North Sea Region. Report commissioned by: Niedersächsischer Landesbetrieb für Wasserwirt-schaft, Küsten-und Naturschutz (NLWKN) and Landesbetrieb für Küstenschutz. Nationalpark und Meeresschutz Schleswig-Holstein (LKN. SH), 65p.

Singh, N. and Turner, A., 2009. Trace metals in antifouling paint particles and their heterogeneous contamination of coastal sediments. Marine Pollution Bulletin, 58(4), pp.559-564.

Strand, J., Tairova, Z., Danielsen, J., Würgler Hansen, J., Magnusson, K., Naustvoll, L., and Sørensen, T.K., 2015. Marine Litter in Nordic waters. Report for Nordic Council of Ministers, 79 p.

Stuer-Lauridsen, F., Jensen, M.P., Odgaard, T., Husum, H., Olsen, D., Ringgaard, J.W., 2007. Ship Dismantling and Precleaning of Ships, European Commission Directorate General Environment, Final report, June 2007. 172p.

Sundt, P., Schulze, P.E. and Syversen, F., 2014. Sources of microplastic pollution to the marine environment. Report for the Norwegian Environment Agency No. M-321-2015, 86p.

Sundt P., Schulze P.-E., Skogesal, O., and Syversen F. 2016. Primary microplastic-pollution: Measures and reduction potentials in Norway. Norwegian Environment Agency Report No. M-454-2016, 117p.

Sunt et al., 2021. Norsk land baserte kilder til mikroplast. Norwegian Environment Agency Report No.

Sørensen, L., and Almås, K., 2020. Identifikasjon av plastpellets i forbindelse med aksjon Trans Carrier - Sammenligning av prøver fra felt med kildeprøve. SINTEF Report, OC2020 A-103. 17p.

Thomas, K.V., Brooks, S., 2010. The environmental fate and effects of antifouling paint biocides. Biofouling 26, pp. 73–88.

Tornero, V. and Hanke, G., 2016. Chemical contaminants entering the marine environment from sea-based sources: a review with a focus on European seas. Marine Pollution Bulletin, 112(1-2), pp.17-38.

Turner, A. and Rees, A., 2016. The environmental impacts and health hazards of abandoned boats in estuaries. Regional Studies in Marine Science, 6, pp.75-82.

Turner, A., Arnold, R. and Williams, T., 2020. Weathering and persistence of plastic in the marine environment: Lessons from LEGO. Environmental Pollution, p.114299.

UNEP 2009. Marine Litter: A global Challenge. UNEP, Nairobi. 232 p.

UNEP. 2016. Marine plastic debris and microplastics –global lessons and research to inspire action and guide policy change. UNEP, Nairobi. 192p.

Unger, A. and Harrison, N., 2016. Fisheries as a source of marine debris on beaches in the United Kingdom. Marine Pollution Bulletin, 107(1), pp.52-58.

Vangelsten, B.V., Bay-Larsen, I., Nogueira, L.A., Pedersen, V., 2019. Delrapport Havplast, Marint avfall fra havbruksnæringen. Nordlandsforskning rapport Nr. 10/2019.

von Friesen, L.W., Granberg, M.E., Pavlova, O., Magnusson, K., Hassellöv, M. and Gabrielsen, G.W., 2020. Summer sea ice melt and wastewater are important local sources of microlitter to Svalbard waters. Environment International, 139, p.105511.

Wind Europe, 2020. Offshore Wind in Europe. Key trends and statistics 2019. Report published February 2020. 40pp. Available at: https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2019.pdf

Xue, B., Zhang, L., Li, R., Wang, Y., Guo, J., Yu, K. and Wang, S., 2020. Underestimated microplastic pollution derived from fishery activities and "hidden" in deep sediment. Environmental Science & Technology, 54(4), pp.2210-2217.

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