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Sources of microplastic-pollution to the marine environment

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Project report

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The overall objective of this study ordered by the Norwegian Environment Agency is to provide a good overview of the different sources contributing to microplastic pollution both in Norway and globally. For Norway, we also provide a first assessment of the type and amount of microplastics each source contributes.

Importantly, we characterize the microplastic sources only at their upstream origin, ideally just where the microplastic particles start their "life" as environmental pollutants, for example at "the start of the pipe", on land or at sea.

The report analyses and estimates the emissions/littering from both primary and secondary sources of microplastic pollution. For primary sources, we estimate the annual emissions in Norway at about 10.000 tons. For secondary sources, it is not possible to make an estimate. However, the report concludes that both sources are important for the generation of microplastics in the Norwegian oceans.

The definition and understanding of "microplastics" is crucial and therefore discussed thoroughly in Appendix B. Mepex has also developed a conceptual model for different kinds of microplastic sources, presented in chapter 5.8, giving the reader a systematic overview of sources.

It is necessary to underline that the calculations made in this report are our best estimates, based on defined assumptions and often, poor data. In some cases, industry has taken an active part and helped providing data. In other cases, industry is not even aware of the microplastic issue or do not want to involve themselves. It is also likely that some areas of pollution may also have been overlooked by the authors of this pre-study.

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1. Summary

1.1. General summary

Microplastic is plastic fragments smaller than 5 millimeters. These are fairly recently discovered in high and increasing concentrations in the ocean, and there is a large international focus on identifying their sources and fate in the sea.

Mepex have made an initial assessment of potential sources to micro-plastic pollution of the marine environment for the Norwegian Environment Agency. Through review of international literature and further studies in Norway we have identified microplastic emissions both from the production, use, maintenance and disposal of plastic-containing products.

Total volume of Norwegian annual emissions from primary sources is estimated at approximately 8.000 tonnes of microplastics (1.6kg per capita), a significant proportion of which are considered to have the potential to reach water bodies and the ocean. Some of this is also released directly into the sea.

Abrasion from tires and roadmarking accounting for the formation of about 5000 tonnes per year is the largest source. This estimate is based on reliable information. Associated with more uncertainty are the volumes of the estimated second-largest emissions category, dust and particles from plastic based paint when applied, weathered or maintained both on buildings, structures, ships and yachts. Robust information from the industries regarding paint use in Norway, plastic content, and wear rate of the products is lacking. A rough estimate based on emission factors from OECD estimates developed by international experts in the industry suggests the potential for emissions of ≈1000 tonnes considered plastic alone (other auxiliary substances in the product were subtracted). City stormwater effluent and road runoff could be a major pathway for microplastics.

Furthermore, we have identified potential emissions both during plastic production (over 400 tonnes) and various types of waste treatment that may involve plastic (over 500 tonnes). Direct use of micro plastic particles in consumer products, especially body care and cosmetics, are a significant source of emissions via wastewater (≈40 tonnes) but emissions of plastic fibers from washing synthetic fabrics is an order of magnitude higher (at worst ≈1000 tonnes down the drain). These plastic fibers are also spread via indoor air and house dust. In indoor dust there will also be plastic particles from household surfaces and plastic objects. The finer particles are particularly likey to reach the sea via sewage or via air.

There is little knowledge from most industry sources contacted about whether their activities could result in microplastic discharge or not, and to what extent their emission control treatments capture microplastic. There is similarly a lack of knowledge regarding emissions of macroplastic, *i.e.* large plastic trash into Norwegian waters, which could degrade and fragment into microplastics.

We have not found any existing estimates of the Norwegian plastic pollution of the sea, but estimates based on international knowledge adapted to Norwegian conditions may be in the range of 10,000-20,000 tonnes annually. Of this, important single sources of plastic waste are: recreational activities both on land and at sea, loss and dumping of plastic from the fishing, shipping and aquaculture industries, as well as sewage and stormwater related pollution episodes. Input from long-range transport and mass balance for marine macrolitter

is difficult to establish. There is not enough knowledge about how fast plastic trash degrades into microplastics, although studies suggest that on beaches with a lot of sun exposure and wear, defragmentation may be in the range of 1-5% of the standing stock of macroplastic, by weight, annually. It is therefore not possible yet to estimate the contribution from macrolitter to Norwegian emissions of microplastic other than to say that it most likely is substantial.

The main conclusion is that both direct emissions of microplastic, and pollution with plastic waste which in turn fragments into microplastics, are both significant Norwegian sources of microplastic pollution to the ocean. The sources identified add a tremendous amount of microplastic particles in a wide range of sizes and of many different plastic types to the sea.

1.2. Key knowledge gaps and need for further studies

Microplastic pollution is a relative new environmental challenge. This pre-study has estimated both primary and secondary sources for this pollution. However, we have based the estimates on several assumptions and data of poor quality. It is thus important to regard the results purely as a first indication of sources.

In order to obtain a better understanding of the issue of microplastics and develop better estimates on the different sources, we need as a first priority, more elaboration on the definitions of microplastics and criteria for what are microplastics, including a definition of "solid particles". In addition, we need a better overview of microplastic at different particle sizes, even nano particles and particles larger than 5mm. Such an overview can also serve as basis for a better understanding of the defragmentation processes.

Furthermore, we need more research on the different sources of pollution. We propose that more research should focus on the most important sources found in this study, both primary and secondary sources. Chapter 9 brings a list of gaps and proposals for further studies.

1.3. Sammendrag på norsk

Mikroplast er plastfragmenter mindre enn 5 millimeter. Slike er ganske nylig funnet i høye og økende konsentrasjoner i havet, og det er stort internasjonalt fokus på å identifisere kilder og videre skjebne i havet. Mepex har for Miljødirektoratet gjort en første kartlegging av mulige utslippskilder til mikroplastforurensning av marint miljø. Gjennom litteraturstudie internasjonalt og nærmere undersøkelser i Norge er det identifisert tilførsler til miljøet av mikroplast både fra produksjon, bruk, vedlikehold og avfallsbehandling av plastholdige produkter. Totalt volum for norske utslipp, fra disse såkalte primære kildene, er estimert til i størrelsesorden 8000 tonn mikroplast, hvorav en betydelig andel regnes for å ha potensiale for å nå vannforekomster og havet. Noe slippes også direkte i sjøen.

Slitasje fra bildekk og vegmarkering utgjør alene dannelse av omkring 5000 tonn per år og er dermed den største kilden. Dette anslaget er blant annet basert på direkteinformasjon fra norske aktører. Det er knyttet mer usikkerhet til volumene for den estimert nest største utslippskategorien, støv og partikler fra påføring, aldring og vedlikehold av plastbasert maling både på bygg, konstruksjoner, skip og fritidsbåter. Her mangler god informasjon fra bransjene om henholdsvis forbruk i Norge, innhold av plast, og slitasjetakt på produktene. Et grovt anslag basert på utslippsfaktorer fra OECD utviklet av internasjonale eksperter i bransjen tilsier potensiale for utslipp av 1000 tonn regnet som plast alene (andre ingredienser i produktet trukket fra). Overvann fra veier og byområder vil kunne føre store mengder av mikroplast fra disse kildene til sjøen.

Videre er det identifisert potensielle utslipp både under plastproduksjon (over 400 tonn) og ulike typer avfallsbehandling som kan involvere plast (mer enn 500 tonn). Direktebruk av mikroplastpartikler i forbrukerprodukter, spesielt kroppspleie og kosmetikk, er en betydelig kilde for utslipp via avløp (om lag 40 tonn), men utslipp av plastfiber fra vask av syntetiske tekstiler er en størrelsesorden høyere (anslagsvis 1000 tonn til avløp). Slike plastfiber spres også til inneluft og husstøv, både privat og i næring og i offentlige bygg. I innestøv vil det også være plastpartikler fra overflater og plastgjenstander. Spesielt de finere partiklene vil kunne nå sjøen via vask og avløp eller luft.

Det er lav kunnskap i de fleste bransjene kontaktet om hvorvidt deres aktiviteter vil kunne medføre mikroplastutslipp eller ikke, og i hvilken grad renseanordninger, f.eks. i avløpssystemet, fanger opp mikroplastutslippene. Begrepet mikroplast er for mange uklart og tolkes også ulikt. Rapporten belyser derfor begrepet grundig og konkluderer med at begrepet bør forklares bedre for å oppnå en bedre forståelse, også i næringslivet.

Tilsvarende lav kunnskap gjelder også for utslipp av makroplast, altså større plastsøppel til norske havområder som igjen vil kunne nedbrytes og fragmenteres til mikroplast. Vi har ikke funnet noen eksisterende anslag på norsk plastforsøpling av havet, men anslår selv at det basert på internasjonal kunnskap tilpasset norske forhold vil kunne være i størrelsesorden 10.000-20.000 tonn årlig. Av dette er viktige enkeltkilder plastsøppel fra fritidsaktiviteter både på land og til havs, tap og dumping av diverse redskap laget av plast fra fiskeri, skip og oppdrett, samt kloakk- og overvannsrelaterte forsøplingsepisoder. Tilførsler av plastavfall fra andre land og havområder, samt massebalanse for plastsøppelet (inn-ut av Norge, synke eller flyte) er foreløpig vanskelig å anslå. Det finnes heller ikke nok kunnskap om hvor fort plastsøppel brytes ned til mikroplast, selv om studier antyder at det på strender med mye soleksponering og slitasje på avfallet kan være i størrelsesorden 1-5% årlig. Det er derfor ikke mulig ennå å anslå makroplastens bidrag til norske utslipp av mikroplast annet enn at de vil være betydelige.

Hovedkonklusjon er at både direkte utslipp av mikroplast og forsøpling med plastavfall som så fragmenteres til mikroplast er betydelige norske kilder til mikroplastforurensning i havet. Kildene identifisert tilfører en enorm mengde partikler i et stort spenn av størrelser og fra mange plasttyper.

2. Introduction

What are the most significant discharges and emissions of microplastics into the oceans? In this report we review the current knowledge about sources of microplastic pollution, and add results from our own investigations of upstream microplastic sources using Norway as a case study.

Marine littering and microplastics are regarded as a global environmental problem. As the ocean has no borders, debris and microplastics can potentially be spreading globally. Most of the existing research effort to date has covered the abundance of plastic particles in different marine sites and ecosystems. As we often observe in environmental studies, pinpointing actual pollution sources is less common.

Pollution of the marine environment by microscopic plastic particles may be regarded as a relatively "new" environmental problem. During recent years, this pollution has received progressively increasing attention, both among scientist and the general population, in the media, and by national and international authorities. Though a few scientific articles from the early 1970's and onwards reported finding small plastic fragments inthe sea[1], it was first in 2004 that "microplastic" was introduced as a scientific term by Thompson *et al.*[2] in the journal Science[3].

Microplastic pollution is generally defined as plastic fragments smaller than five millimetres in any dimension, and is often categorized as either primary or secondary microplastic. Primary microplastic are made and emitted as micro particles. Examples are the abrasive microbeads in face scrubber cosmetics, or plastic raw material granules used in manufacturing (also called "mermaid tears" and nurdles). Secondary microplastic is formed in the marine environment when macroplastic litter is fragmented to ever smaller pieces by weathering.

Microplastics are now found in all oceans[4], in the most remote locations[5] and at all depths[6]. It has been demonstrated both in the laboratory and in nature that microplastic can be taken up by animals. Effects are still largely unknown but are increasingly the subject of scientific scrutiny, as microplastic pollution is suspected to rapidly increase in the oceans in the future[7]. There are increasing trends of microplastics in time series of samples at many

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[1] For example: Carpenter, E. J., Anderson, S. J., Miklas, H. P., Peck, B. B., & Harvey, G. R. (1972). Polystyrene spherules in coastal waters. Science, 178(4062), 749-750. ; Colton, J. B., Knapp, F. D., & Burns, B. R. (1974). Plastic particles in surface waters of Northwestern Atlantic. Science, 185 (4150), 491-497. ; Derraik, J. G. B. (2002). The pollution of the marine environment by plastic debris: a review. Marine Pollution Bulletin, 44(9), 842-852.

[2] Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D., & Russell, A. E. (2004). Lost at sea: Where is all the plastic? Science, 304(5672), 838-838.

[3] According to review by Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. Environmental Science & Technology, 46(6), 3060-3075.

[4] Extensive review by: Sul, J.I.L., & Costa, M.F. (2014) The present and future of microplastic pollution in the marine environment. Environmental Pollution 185, 352-364.

[5] For example: Free, C. M., Jensen, O. P., Mason, S. A., Eriksen, M., Williamson, N. J., & Boldgiv, B. (2014). High-levels of microplastic pollution in a large, remote, mountain lake. Marine Pollution Bulletin, 85, 156–163. ; Obbard, R.W., Sadri, S., Wong, Y.Q., Khitun, A.A., Baker, I., & Thompson, R.C. (2014). Global warming releases microplastic legacy frozen in Arctic Sea ice. Earth's Future, 2, 315–320.

[6] Van Cauwenberghe L. , Vanreusel, A. , Mees, J., & Janssen, C.R. (2013). Microplastic pollution in deep-sea sediments. Environmental Pollution, 182, 495-499.

[7] For example: Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B-Biological Sciences, 364(1526), 1985-1998.

locations, both from open ocean[8], biota such as seabirds[9] and in the sediment record[10].The increase is tracking the trend of global plastic production.

From recent pilot studies in the open sea of the Northeast Atlantic, the concentration of microplastic (in that study size range 250 micrometres – 5 mm) is above 2 particles m^3 [11], while in coastal waters of the Skagerrak it might be tens or hundreds of thousand per m^3[12]. In beach and sediment surveys in the North Sea area, concentrations of several hundred microscopic plastic particles per kg of sand have been recorded[13]. Understanding the source of these microplastics is a key question to European ocean management[14][15].

The issue of marine littering and microplastics is hence put on the international agenda, by the UN and IMO[16], NGOs[17] and the plastic industry (for example Plastics Europe). In the Nordic region, bodies like the HELCOM, the Nordic Council and the EU[18] and OSPAR[19] have raised concerns over marine microplastics pollution. As can be seen from the bibliography (Chapter 9), some tens of reports and some hundreds of scientific articles have been made during the last few years on microplastics as a component in marine litter.

Norway's southern part is located in the North Sea, a densely populated and polluted area of the North East Atlantic. All countries around the North Sea, about 200 million people, contribute to marine littering. Further, Norway has a long coastline orientated north-eastwards, including Spitsbergen, intersecting the Norwegian Sea, the Barents Sea and the Arctic. The coast and the ocean are of vital importance for Norwegian society, culturally and economically, including industries such as fisheries, shipping and tourism.

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8 Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D., & Russell, A. E. (2004). Lost at sea: Where is all the plastic? Science, 304(5672), 838-838.

9 Robards, M. D., Piatt, J. F., & Wohl, K. D. (1995). Increasing frequency of plastic particles ingested by seabirds in the subarctic North Pacific. Marine Pollution Bulletin, 30(2), 151-157. ; Ryan, P. G. (2008). Seabirds indicate changes in the composition of plastic litter in the Atlantic and south-western Indian Oceans. Marine Pollution Bulletin, 56(8), 1406-1409.

10 Claessens, M., De Meester, S., Van Landuyt, L., De Clerck, K. & Janssen, C.R. (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. Marine Pollution Bulletin, 62, 2199-204.

11 Lusher, A.L., Burke, A., O'Connor, I., & Officer, R. (2014). Microplastic pollution in the Northeast Atlantic Ocean: Validated and opportunistic sampling. Marine Pollution Bulletin, 88 (1-2), 325-333.

12 Norén, F., Norén, K. & Magnusson, K. (2014). Marint mikroskopiskt skräp. Undersökning längs svenska västkusten 2013 & 2014. (Report, in Swedish). IVL. Rapport 2014:52. Länsstyrelsen i Västra Götalands län, Vattenvårdsenheten.

13 Reviewed by Leslie, H.A., van der Meulen, M.D., Kleissens, F.M. & Vethaak, A.D. (2011). Microplastic litter in the Dutch Marine Environment. Deltares-IVM report 1203772-000. The Netherlands, 85 pp.

14 Depledge, M. H., Galgani, F., Panti, C., Caliani, I., Casini, S., & Fossi, M. C. (2013). Plastic litter in the sea. Marine Environmental Research, 92, 279-281.

15 Zarfl, C., Fleet, D., Fries, E., Galgani, F., Gerdts, G., Hanke, G., & Matthies, M. (2011). Microplastics in oceans. Marine Pollution Bulletin, 62(8), 1589-1591.

16 The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), established in 1969, advises the United Nations (UN) on scientific aspects of marine environmental protection. Working Group 40, looks into the sources, fate and effects of microplastics in the marine environment.

17 About 30 Norwegian NGOs are involved in beach cleaning activities, art projects or other public awareness campaigns about marine litter. Source: Hold Norge Rent (2014). Hvordan styrke opprydningen av marint søppel - en oversikt over aktuelle aktører, vurdering av organisering og mulige samarbeidstiltak. (Report, in Norwegian.)

18 Based on the Marine Strategy Framework directive (MSFD) the EU has established a Technical Subgroup on Marine Litter which has published guidance on monitoring marine litter in European Seas. The EU- Commission also proposed, as part of the Circular Economy package, on 2 July 2014, prevention target for marine littering of 30% within 2020 (related to 10 most common products in beach surveys, compared with 2015).

19 OSPAR, the regional Sea Convention for the North Sea, is in the process of developing a Monitoring Framework complimenting monitoring for the MSFD. In 2013, OSPAR decided to adopt beach litter as a common indicator; ingestion in fulmars as a common indicator in the Greater North Sea area. OSPAR has developed an action plan and established working groups in order to follow up the actions. Activity 46 relates to microplastics, also monitoring littering from rivers. Action 42 covers sewage and storm water, also inclusive micro particles.

As marine littering is a potential environmental, health and economic threat, the prevention of marine littering is listed as a challenge in the Norwegian Waste Strategy, launched in 2013, as well as different regional water management plans. To get a better foundation for future work on microplastic problem, the Norwegian Climate and Environment Ministry in 2014 commissioned the Environment Agency to provide an evaluation of microplastics in the marine environment as a threat to health and the environment. The present report is part of this evaluation, and its focus is narrowed in on pinpointing and weighing different microplastic pollution sources. Other "downstream" topics, such as the fate, distribution and effects of microplastics in the ocean, and the sewage system as a pathway for emissions, are covered by other subprojects and reports. Based on these reports the Environment Agency will outline the need and direction for more studies or management measures.

3. Aim and scope of study

The overall objective of this desktop study ordered by the Norwegian Environment Agency is to provide a thorough overview of the different sources contributing to microplastic pollution both in Norway and globally. In particular for Norway, the report will also provide a first assessment of the type and amount of microplastics each source contributes.

The intention of this report is to identify and describe the 15-20 key sources of microplastic pollution to Norwegian seas, with the ambition to cover 80-90% of the national emissions. To a certain extent we also describe other relevant sources to the North Sea.

Importantly, we characterize the microplastic sources only at their upstream origin, ideally just where the microplastic particles start their "life" as environmental pollutants, for example at the "start of the pipe". By applying this definition of sources we leave it to other studies to describe pathways of distribution downstream in the effluent system, the waterways and the sea. Rivers and effluent (including sewage treatments plants) are important pathways and transit spots for micropollutants such as microplastic, but not included as sources by our definition and in this report. The sources included by this definition are structured according to type of activity/ management sector rather than by geography (region) or by specific waterway/ rivers.

We mention findings about sources from effluent or the environment only to the extent they contribute in identifying and understanding the upstream sources. For known microplastic sources we go into some detail on their origin and estimated contribution, while small or poorly documented sources are just given a short mention.

The definition of "microplastics" used for this report is summarized in the table 3-1 below. For in depth discussion see appendix B.

Table 3-1 Microplastics in brief

General characteristics	Comments
Solid phase material	Solid particulates, not fluid/ liquid. Includes particles in suspensions. But harder than particles in waxes. Some polymers are not solid.
Insoluble in water	Lack of knowledge on degradation in water, so "insoluble" is to understand as a relative term.
Synthetic	Often polymers can be regarded as "synthetic", but not always, better wording might be "man- made" polymers
Slowly degradable	Some plastics claim they are "biodegradable", other plastics degrade slowly, for example in the sun.
Made from plastics	Possibly also other "particles made from polymers" should be included, as long as the particles are solid.
Small size < 5mm	Includes very small particles, even nano. Particles can have all kinds of shape.

4. Methods

The study comprises three methodologies:

1. A literature review, mainly of scientific peer-reviewed articles.
2. Compiling information from other relevant sources, by interviews and documents.
3. Calculations and assessments, simple mass-flow analyses based on available data

For details about methods, see appendix D.

The rate of pollution will be described quantitatively as total national emission in tonnes per year for every key source, and where quantitative estimation was not possible, assessment was given as a qualitative weighting.

We have taken a mass flow approach, and ideally the sources would then be estimated based on real data of national use of a material combined with a reliable emission factor for each source based on a statistically reliable dataset. Most often this is not available for microplastics. Where ever possible we have still tried to give an estimate even if some untested assumptions and default values have to be included. These are clearly stated, so that the calculations can be refined as knowledge of the source progresses.

For traditionally well known plastics, all volume estimates are to be understood as the full weight of the plastic product (including whatever additives it might contain which would add weight), while for uses of plastics as additives in other products, such as for example asphalt, paint or rubber, we provide weight as polymer content alone (subtracting for example fillers and other constituents that otherwise would inflate the estimates).

As a general and simplifying assumption for all estimates, we have not included any timelag between products entering the market and becoming waste/microplastics, but used emission factors directly on the latest known use volumes.

5. General findings and overview of microplastic sources in Norway

A pollution source needs a name and an address. Identifying and assigning the name and address of microscopic pollution experienced far out at sea is, however, not easy. Microplastic particles drifting in the open sea would be a mix of many different sources, from different locations, emitted at different times and in different stages of degradation. Similar to other persistent micro- and chemical pollutants, we might assume that a large part of the pollution we see today is actually of historical origin. It is a result of "old sins" and the polluter, whether a private person or an entire industry, might not even exist anymore.

Some scientific authors state it is virtually impossible to identify microplastic sources. Still, among the more than 100 scientific, peer-reviewed articles with microplastic as a major topic, about a dozen provide qualified contributions to the identification of sources.

As a starting point, we see that a few microplastic sources are regularly mentioned, probably because they are very obvious. However, there is surprisingly little information on exact emission rates from different sources. For example, from natural defragmenting of plastic macrolitter, plastic microbeads from consumer products, and "mermaid tears"/pellet loss from plastic production. Microfibers emitted from the laundry also seem an obviously important source, but have received much less attention. Similarly, paints and city dust have also only very recently received attention as potential microplastic sources[20].

One of the reasons no field researchers have landed any overall conclusion about the relative contribution of different microplastic sources is a sampling problem. It is the same reason why it is difficult to estimate, for example, plankton abundance in the sea: because it is highly variable at several spatial scales[21] due to different physical oceanographic features, like currents. Also different plastic types, shapes and particle sizes have different buoyancy and floating behaviour in the turbulent ocean environment.

Specific gravity (or density) is an important property related to microplastics behaviour in water. In the table 5-1 below, different polymers are listed according to their specific gravity. The table also lists the percent share of the total market demand for plastics in Europe (EU 27 countries +Norway and Switzerland) in 2012. Common applications are also listed in the table. Most of these plastic types are mentioned in studies on microplastic pollution. According to recent reviews, Polyethylene (PE) is mentioned in 33 studies, Polypropylene(PP) in 27, Polystyrene (PS) in 17 and Polyamide (PA) in 7[22]. The others are mentioned in 0-4 studies each. PE and PP are mentioned the most and these two plastic categories have the lowest specific gravity and a combined contribution of almost 50% of all plastic production in Europe.

Typically, lightweight litter based on, for example, polyethylene or expanded polystyrene (EPS) will float downstream and be carried far away at the ocean surface, while heavier

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[20] These sources are for example included with mentions in the recent report by Verschoor, A., de Poorter, L., Roex, E.,& Bellert, B.(2014). Inventarisatie en prioritering van bronnen en emissies van microplastics. RIVM Briefrapport 20140110. (In Dutch, with English summary). Netherlands.

[21] Goldstein, M.C., Titmus, A.J., & Ford, M. (2013). Scales of Spatial Heterogeneity of Plastic Marine Debris in the Northeast Pacific Ocean. PLoS ONE, 8(11), e80020.

[22] JRC Scientific and Policy Reports (2013). Guidance on Monitoring of Marine Littering in European Seas.

plastic litter will sink into sediments soon after the effluent point[23]. This is seen both for macro- and microplastic litter, as lightweight polyethylene dominates at distant oceanic beaches far from any point sources, while heavier particles like nylon, polystyrene and acryl are more common near the point sources. Marine fouling further confuses the picture, by adding weight enough to make even positively buoyant plastics sink after some time in the sea.

Table 5-1 Specific gravity of some plastics. Items with less specific gravity than seawater will float.

Categories or classes	% of market	Common applications	Specific gravity
Polyethylene (PE)	29,5	Plastic bags, bottles, six-pack rings, gear, cages and pipes for fish farming	0.91-0.94
Polypropylene (PP)	18,8	Rope, bottle caps, gear, strapping	0.90-0.92
Styrene Butadene Rubber SBR	-	Roofing felt and car tyre	0.94
Polystyrene (expanded) (EPS) * (part of PS %)	*	Bait boxes, floats, cups , expanded packaging	0.01-1.05
Seawater			~ 1.02
Polystyrene (PS)	7,4	Utensils, containers, packaging	1.04-1.09
Acrylonitrile Butadiene Styrene (ABS)		Electronics and electrics, car interior	1.03-1.11
Acrylic	-	Paints, packaging	1.09-1.20,
Polyvinyl chloride (PVC)	10,7	Film, pipe, containers , buoys	1.16-1.30
Polyamide or nylon (PA)	-	Gear, fish farming nets, rope	1.13-1.15
Polyurethane (PUR)	7,3	Insulation	1.2
Poly(lactic acid) (PLA)	-	Packaging, cups, mulch fim	1.21-1.43
Cellulose acetate	-	Cigarette filters	1.22-1.24
Polyethylene terephthalate (PET)	6,5	Bottles, strapping, gear	1.34-1.39
Polyester resin + glass fibers	-	Textiles, leisure boats	>1.35
Polytetrafluorethylene PTFE (aka Teflon)	-	Personal care products	2.2

The microplastic particle sizes would also influence the transport potential of the microplastic pollution. Microplastics rarely appear alone as single items; they exist in a “plastic soup” or “plastic sand” in nature. That is, a mix of plastic particles of different sizes and types. This is further complicated by the same sources also emitting a wide range of plastic sizes. For most of the microplastic sources we have found and provide details on in the following chapters, it is not possible to identify a narrow particle size range. Hence, particle sizes seem to have limited value in pinpointing concrete sources except for a few and volume-limited uses of very specifically shaped and sized microbeads and microspheres. Also, source estimates based on particle counts alone, without any size range information, give little meaning when assessing the emission volume.

When interpreting field studies for pollution source related information, it is very important to keep in mind that in this emerging field different researchers have looked at slightly different categories of microplastic particles, often depending on their preferred sampling and particle identification techniques, or on their preferred microplastic source in focus. For example, different mesh sizes of filter or sampling net would largely influence what “catch” you get. This might create confusion when comparing studies. Some studies have for example missed out on most of the small particles, and by doing so have excluded certain

[23] This was realized early, for example by Morris, R. J. (1980). Plastic debris in the surface waters of the South Atlantic. Marine Pollution Bulletin, 11(6), 164-166. It is confirmed by most later studies we have reviewed.

sources. Others have sampled just at the surface, excluding all sources of more dense plastic types.

Good emission estimates and weighting of different sources thus also requires estimates from upstream knowledge of the microplastic material flow, not only estimates from field observations. When tracking down microplastic sources it is certainly a good idea to think about potential losses from the plastic value chain, as illustrated in Figure 5-2 below, from raw material production, left, to waste treatment to the right. Marine littering is often described as lost and illegally discarded plastic waste, however, losses of microplastics are also from raw material production, recycling and the use and maintenance of the plastic products.

Table 5-2 A simple illustration: spills of microplastic from the plastic value chain

(Unintentional) Production Spill	**Designed spill of product**	**Wear and Tear during use**	**Abrasion by commercial maintenance**	**Waste shredding**	**Macrolitter**
Spill of plastic particles happens at every step in lifecycle					

Hunting down the most important pollution sources is thus about finding a "match" between what you observe as pollution in the field, and a suspected potential source in the plastic value chain. This requires site specific sampling designed to say something about sources, certain investigative techniques (sometimes even forensic), the application of chemical and physical fingerprinting, and a certain level of knowledge about the unique features of each potential pollution source. Useful tools we see increasingly being applied in tracking down potential sources from microplastics found in the environment are:

- Forensic microscopy (high resolution, even electron scanning microscopy)
- Tools for identifying the plastic type of single particles observed
- Different "chemical fingerprinting" by analysis of plastic additives, monomers etc. present in single particles or in samples

For every pollution source identified in this chapter, we will first give an introduction to the qualitative knowledge about the source before we describe in more detail each significant source group, providing critical quantitative data and pointing at data gaps.

5.8. Conceptual model for microplastic pollution sources

During this study we have developed a conceptual model based on the initial findings, see Table 5-3 below, in order to organize different microplastic sources by sectors, source groups and identifiable single sources. We introduce several categories within respectively primary sources and secondary sources in order to better grasp the different modes and mechanisms of microplastic pollution. This model has been tested out and discussed with several stakeholders in the market during the project. The model has enhanced a good dialogue and a systematic approach on the topic of pollution sources, and the structure could be further developed with stakeholder input.

Table 5-3 Conceptual model of mechanisms and differets sources of microplastic pollution

Main mechanism	Main source	Subgroup	Identifiable single source
Primary sources A) Microplastic intentionally created	**Consumer products** with "open use" plastic microbeads and microspheres,	Exfoliating Personal Care Products (PCP)	Exfoliating beads in e.g. face and body wash, toothpaste
		Other PCP products	Microbeads for e.g. slip or bulking effect, or microspheres in e.g. shave foam, lipstick, sunscreen, mascara
		Other consumer products	E.g. glitter powder, antiskid powder, printer toner
	Commercial or industrial use products and intermediates containing microplastic for open or semi closed applications	Abrasive media in metal works	Plastic blasting grit for sandblasting at shipyards, offshore maintenance, production facilities
		Abrasive media in other processes	Plastic blasting grit used at different production facilities, e.g. for garment, car parts, tools
		Processing industry	Specialty chemicals with plastic microbeads, e.g. oil and gas exploration, textile printing,
		Medical applications	Dentist tooth polish and medical applications of plastic beads or spheres in e.g. medicines (Ugelstad monobeads)
B) Microplastic as an inherent byproduct of product or process	**Microplastic dust emissions from industrial production or maintenance** of macro plastic items.	Commercial handling or maintenance on plastic items	Dust from cutting, polishing and molding plastic items e.g. at boat repair- and shipyards, car repair shops, ski waxing workshops
		Point sources: maintenance on plastic painted maritime surfaces	Plastic dust emissions from painting, sandblasting, high pressure wash and more at shipyards.
		Diffuse sources from maintenance of plastic treated surfaces	Dust from paint application and maintenance work on other painted metal constructions: bridges, buildings, pipelines, offshore rigs
	Dust and fibers from wear and tear of plastic products during normal use	Household dust emissions,	Plastic dust from the abrasion or weathering from plastic items indoor at home, e.g. paints textiles, toys and EE, furniture and floor covering.
			Textile fibers ripped loose in laundry machine and driers
			Private paint removal by scrubbing, heavy duty wash

Main mechanism	Main source	Subgroup	Identifiable single source
		City dust emissions	Plastic particles in road-dust from road paint, tires, polymer modified bitumen
			Dust from weathering of plastic treated exterior surfaces (paints, sealants,)
		Indoor dust emissions from commercial or public constructions and buildings.	Particles from abrasion or weathering of plastic pipeline systems
			Office dust and similar, e.g. wall-to-wall carpeted rooms, copy- and print rooms, heavy abrasion on furniture and surfaces in publicly accessible buildings.
			Effluent from commercial laundries and cleaning companies
		Agriculture	Degrading agrifilm/Mulch film
		Maritime sector, Aquaculture, fisheries	Abrasion and weathering of plastic ropes and surfaces in harbors
			Effluent from aquaculture and fishing net cleaning facilities
	Waste handling and recycling creating microplastic particles	Plastic particles from shredding and fragmenting plastic waste	Composting plastic contaminated organic waste, and runoff from reuse of this
			Improper use and handling of shredded WEE and ELV fluff and fractions
			Food waste shredders on ships and institutions
			Shipbreaking/decommissioning of ships and offshore installations
C) Unintentional release	Transport	Accidental release/loss	Granules/Pelleted plastic raw materials/regranulates
	Fires and illegal waste burning		Dust emissions from fires and uncontrolled burning
Secondary sources A) Natural defragmenting of macro plastic debris in the sea.	**Macro plastic debris from illegal, unwanted or unregulated terrestrial waste handling**	Municipal landfills	Air drift of plastics if not well covered
			Plastic particles in water effluent
		Industrial and construction waste	Dumping of construction and process waste
		Private illegal landfills	Illegal landfills
		Littering in public spaces	Parks, recreational spots, roadsides renovated by municipalities

Main mechanism	Main source	Subgroup	Identifiable single source
	Macro plastic debris from illegal, unwanted or unregulated maritime waste handling.	Fishery	Waste thrown over board
			Loss of trawls, nets
		Aquaculture	Abandoned equipment and sites
			Storm loss of floaters
		Shipping and offshore	Waste thrown overboard or items lost
			Weathering and defragmenting of wrecks and abandoned vessels
		Seaside leisure activity and recreational boating	Plastics thrown away directly to the sea when boating, recreation outside public area
	Municipal effluent (Sewage system and storm water)	Public sewage treatment plants	Macro plastics passing mechanical filters, e.g. Q-tips, condoms, cigarette buds.
			City surface water drains
	Runoff from terrestrial sources	Regular riverine input	Macro plastic waste emitted directly to lakes and rivers
		catastrophic events, unintentional loss	Plastic macro waste brought adrift from land during extreme flooding and storm .
B) Biological contribution to defragmenting of microplastics	Shredding by animals		Grinding of plastic into microplastic in the gizzard (gastric mill) of abundant macro fauna
	Boring by animals		Creation of microplastic particles by boring isopods
	Animals contributing to increased weathering of marine plastic debris		Seabirds bringing rope pieces ashore, using them as nesting material. Susceptible to rapid UV degradation.
C) Remobilization	Harbors		Ship propellers reworking sediments
			Dredging plastic contaminated sediment
	Construction sites		Excavating plastics contaminated soil. Reuse of construction materials/waste

Literature often splits microplastic sources of pollution into primary sources: the direct input to the environment of microsized plastic particles from human activities, and secondary pollution sources: the breakdown and defragmenting of macroplastic litter to microplastic in the ocean. This is in line with classical definitions about pollution in general: primary sources are fresh emissions, often manmade, while secondary sources are when pollutants already in the environmental pool, being moved around and reintroduced into the environment.

There is some confusion arising from some studies on microplastics when using the term "secondary microplastics" on all other plastic particles than the ones made so by design. Some literature, for example, classifies house dust, textile dust or maritime paint dust as secondary microplastics, due to its origin from wear and tear, not intended as microplastic particles. Still, we think it adds benefit to classify them as primary sources, as long as they are added from human society at the "start of the pipe", and their emissions are inherently a result of human material and product use. We do therefore not use the term "secondary microplastics" in this report, but rather secondary sources where applicable.

Chapter 6 details findings about primary sources of microplastics, while chapter 7 describes the secondary sources; mainly the pathways from macroplastics to microplastics.

6. Primary sources of microplastic pollution

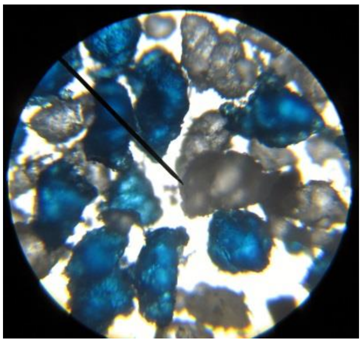
Primary sources are those we understand as adding new plastic material of micro size to the environment. Major microplastic sources covered here are the ones where microplastics are:

A) Intentionally produced and used as such.
B) An inherent by-product of other products or activities.
C) Emitted as such by accidents or unintentional spill.

6.1. Microplastics intentionally created

6.1.1. Personal Care consumer Products

Plastic microbeads for use in exfoliating consumer products are well established as a microplastic source[24]. Since the patenting of microplastic scrubbers within cosmetics in the 1970s, the use of exfoliating cleansers containing plastics has risen dramatically. Important categories are: scrubs/peelings, shower/bath, facial cleanser and toothpaste. Most of these consumer products would be characterised as “open use”. They are intended to be washed off and end in the drain. Several studies have looked at the particle types present in these products, and other suggested finding them downstream in effluent[25 26].



Origin: Personal care products
Number of sources: every household
Plastic types: PE, PMMA, PTFE, PP, Nylon,PET
Haz.additives: n.a.
Particle size, mm: variable 0.001-0.8 depending on product.
Particle shape: irregular spherical
Specific gravity: depending on product, e.g. PE: 0,9, PFTE: 2

Figure 6-1 Short facts about microplastic in personal care products Photo: microbeads in microscope magnification

Sector description consumer products

Cosmetics and personal care products are a retail sector with about 40 years of steady growth in Norway. All these products are often called Personal Care Products (PCP). The total sales volumes of liquid products (2005) (excluding the packing) was estimated at 23.000 tonnes, of which the product categories most relevant for microplastics are toothpaste: 2.500 tonnes, soaps: 6.700 tonnes and shaving foams: 410 tonnes[27].

Hand cleaner soaps based on a content of 4-10 % polyethylene microbeads of 400 micrometer size are one of the early patents and mentions of use of plastic microparticles in

[24] Fendall, L.S., & Sewell, M.A. (2009). Contributing to marine pollution by washing your face: Microplastics in facial cleansers. Marine Pollution Bulletin, 58, 1225-1228.

[25] Castenada, R.A., Avlijas, S., Simard, M.A., & Ricciardi A. (2014). Microplastic pollution in St. Lawrence River sediments. Canadian Journal of Fisheries and Aquatic Sciences, 71, 1–5. ; Eriksen, M. Mason, S., Wilson, S., Box, C., Zellers, A., Edwards, W., Farley, H., & Amato, S. (2013). Microplastic pollution in the surface waters of the Laurentian Great Lakes. Marine Pollution Bulletin, 77, 177–182.

[26] Gregory, M.R. (1996). Plastic 'scrubbers' in hand cleansers: a further (and minor) source for marine pollution identified. Marine Pollution Bulletin, 32, 867-871.

[27] SFT (2005). Kartlegging av omsetning av enkelte miljøskadelige stoffer i legemidler og kosmetikk. Report from the Norwegian Environment Agency. (In Norwegian with English summary.) TA-2128.

personal hygiene products, now known as “microbeads in abrasive scrubs and cleaners”. Interestingly it was also a main objective with the patented design of the product that the light density particles “... are thus more easily flushed and washed away with water” and hence “do not clog the drains” compared to similar products based on, for example, mineral particles.

A recent Dutch review by Leslie[28] and a review of the cosmetics and polymer literature and microbead producer's catalogues reveals that the open use of plastic microbeads and microspheres is not restricted to defoliants. A great number of other uses are mentioned: creams, eye shadow, deodorant, blush powders, make-up foundation, skin creams, hairspray, nail polish, liquid makeup, eye colour, mascara, shaving cream, baby products, bubble bath, lotions, hair colouring, nail polish, insect repellents and sunscreen. Some of these products are clearly high volume products, such as shaving foam. The review underlines, and this is also confirmed by the Cosmetic industry, that plastics, for example PE, can be used in different forms in the products, e.g. not only as a microbeads.

Figure 6-2 Cosmetic products

The market share of the microplastic containing products is not exactly known. According to a survey by the environmental NGO Swedish Naturskyddsföreningen in 2013, they found 49 presumably microplastic containing cosmetic products based on a check in some shops[29], but gave no mention of number of products without microbeads. Norwegian Naturvernforbundet did a similar check in 2014 in all major supermarket chains and some chemists and found a similar number of plastic microbead containing products[30], easily available. Many exfoliating face and body wash products contained microbeads (about half or more of all available in the shop), the same for shaving foams, while for toothpaste most products on the Norwegian market are without plastic microbeads[31]. The brands containing microbeads were both imported and Norwegian brands. The content of plastics is generally easily identifiable in the ingredient list of the product.

The campaign Beat the Microbead based at Plastic Soup Foundation in the Netherlands, with NGO partners in several countries, has established and maintains an international database with personal hygiene products on the world market known to contain microbeads[32].

[28] Leslie, H.A. (2014). Review of microplastics in Cosmetics. Report R14/29. IVM Institute for Environmental studies. 29pp.
[29] Svenska Naturskyddsforeningen (2013). Raklödder till fiskarna. (Report in Swedish, with English summary: http://www.naturskyddsforeningen.se/sites/default/files/dokument-media/summary_marine_litter.pdf)
[30] List available at webpage: www.beatthemicrobead.org/no/produktliste
[31] Personal observation, author.
[32] Webpage: www.beatthemicrobead.org

Emission factors consumer products

The amount discharged from this source would be easily calculated by knowing sale volumes of each product and multiplying with the microplastic ingredient content. However, neither of these pieces of information are publicly available. The concentration of microplastics as ingredient in a few selected cosmetic products has been investigated in a few studies and, as can be seen in Table 6-1, varies a lot from product to product.

Table 6-1 Content of microplastic found by analysis of selected personal care products

Product	Weight % microplastics	Size (mm) of particles	Plastic type	Ref
Face cleaning	1.62-3.04	0.1-0.2	PE	33
Hand cleaning	0.18-6.91	0.1-0.2	PE	*As above*
Face cleaning	0.94-4.2	n.a.	PE	34
Shaving foam	0.1-2	0.005- 0.015	PFTE	35
Tooth paste	0.1-0.4	0.04-0.8	PE	36
Face Scrub	0.4-10.5	0.04-0.8	PE	*As above*
Tooth Paste	2-4	0.014-0.055	PES	37

International estimates on volumes discharged

In the US, According to Gouin et al[38], a reasonable estimate on daily emission of microbeads for hand wash alone, would be about 1 gram per capita, per year. This estimate was based on general sales volumes for hand wash in US and some general assumptions on market share of the microbead products and their content, not verified.

In Europe, an estimate on the overall volume of plastic microbeads used in PCP in Europe is said from industry sources to be 4.000 tonnes per year[39], which would be 8 grams per capita per year.

In Germany, according to the Nova Institute[40], total consumption of cosmetic products amounted to 790.000 tonnes in 2002. Liquid soap and shower gel consumption amounted to 100.000 tonnes. Nova Institute assumes that 15% of the companies within this product group use microplastic particles in 10% of their products with an average content of 10% microplastic particles and concludes with a consumption estimate of 150 tonnes of microplastic particles/year for this product group. Further it is concluded that about 500

[33] Gregory, M.R. (1996). Plastic 'scrubbers' in hand cleansers: a further (and minor) source for marine pollution identified. Marine Pollution Bulletin, 32, 867-871.
[34] 5Gyres (2013). Microplastics in consumer products and in the marine environment. Position Paper and literature review.
[35] Described in several U.S. patents from Gillette Company, and Technical Data Sheet "Microslip" from Micro Powders Inc.
[36] Strand, J. (2014). Contents of polyethylene microplastic in some selected personal care products in Denmark, presented as poster at NMC conference on plastics in the marine environment, in Reykjavik, 24 September 2014. Aarhus University, Dept. Bioscience, Roskilde, Denmark.
[37] Verschoor, A., Herremans, J., Peijnenburg, W., & Peters, R. (2014). Size and amount of microplastics in toothpastes. Plastic particles in toothpaste were 100x smaller than microbeads in facial scrubs. Conference poster by National Institute for Public Health and the Environment. Netherlands.
[38] Gouin, T., Roche, N., Lohmann, R., & Hodges, G. (2011). A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. Environmental Science & Technology 45, 1466-1472.
[39] Plastics Europe, personal communication.
[40] Presentation by Essel, R. (2014). Einsatzmengen von Mikroplastik in der kosmetischen Industrie und Schätzung des Eintrags aus anderen Quellen. Nova Institute, Køln 1st of July 2014.

tonnes of microplastics was used in total for PCP in Germany in 2002, equaling 6.25 grams, per capita, per year.

In Sweden, the input rate of similar looking particles to sewage treatment plants was above 5 per liter[41]. The average per capita emission of water to sewage in Sweden is often regarded as 400 liter per day, giving an average daily per capita discharge of 2.000 particles from PCP. We do though not know the weight of these particles or if they are from PCP.

Emission estimate, Personal Care Products: 40 tonnes microplastic

There is no sales volume information available to make detailed Norwegian estimates of discharge, but looking to the recent German and European estimates a rough estimate would be about 8 grams per capita X 5 million people = 40 tonnes per year.

Calculated in another way: With an assumed content by weight of 2.5% in the product (from Table 6-1), and a normal portion weight of about 2 grams for a PCP[42], each portion would contain 0.05 grams microplastic. If each person in Norway uses a microplastic containing facewash, shaving foam or toothpaste once a day it would amount to 90 tonnes a year. Even without knowing the market shares the estimate of 40 tonnes seems within a realistic range.

Source control measures and trends

Microplastics from PCP are emitted directly to the sewage system with the exception of the share left in the packing. Those microplastics in the sewage system not filtered out in treatment plants (then ending in the sewage sludge fraction) have the potential to rapidly reach the sea.

In the product checks done by NGOs, it was noted that microbead-free products exist on the market for all common uses. According to *Cosmetics Europe*, the industry believes microbeads shall be replaced by better alternatives, and they are about to phase out their use of microbeads, which is also the documented position of leading multinational companies in this sector. Beat The Microbead confirms this by showing statements from a large number of companies about phasing out plastic microbead use[43]. Instead, the industry wants to phase out these particles and replace them with other alternatives, such as polysaccharides, minerals and lacid acid derivates.

In a recent Swedish study including 47 cosmetic companies, 29 answered they are not using microbeads, while 9 out of the 18 companies using microbeads will phase them out in 2015. Most of the others had similar plans for the next few years[44]. In Norway, *Lilleborg* **™**, the only cosmetics producer in Norway, says they do not use any microbeads in their products[45]. The Nordic Green Label, *Nordic Swan* **™**, does not accept microplastics in labelled products. NorgesGruppen, the leading retailer in Norway, do not use any microbeads in their private label products within personal care or detergent. However, some of the suppliers of NorgesGruppen still use microbeads, and only some of them have plans for phasing out microbead use.[46]

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[41] Magnusson, K., & Wahlberg, C. (2014). Mikroskopiska skräppartiklar i vatten från avloppsreningsverk. IVL-rapport B 2208. (Report, in Swedish). IVL Svenska Miljöinstitutet. Sweden.
[42] Personal observation.
[43] Webpage: www.beatthemicrobead.org/no/industri
[44] Rasmussen, Finn, KLF, Norway, personal communication
[45] Vikersveen, Line, Lilleborg, Norway, personal communication
[46] Wesley- Holand, Line, Norgesgruppen, Norway, personal communication

6.1.2. Industrial or commercial products

While the use of primary microplastics in consumer products constitutes millions of small sources, often called "diffuse sources", the commercial- or industrial-use of similar products can be expected to constitute significant point sources of microplastics. From the microplastics literature, very few commercial-use products with primary microplastics are documented: abrasive blasting media for cleaning metal surfaces, abrasive hand cleaner soaps[47], and brief mentions of some unspecified use in petroleum industry[48].

Some known commercial sectors with use of microplastics

Abrasive blasting media based on plastic beads
These are "mild" alternatives to sandblasting grit based on harder, more aggressive particles. Plastic blasting is hence a preferred surface cleaning media used by, for example, the US Air Force[49], and in some mechanical workshops where it is used on items where it is important that the blasting media does not damage the surface. The beads are supposed to be recycled to some extent, and dust-proof blasting cabinets exist on the market. Such semi-closed or closed use is known, for example, with tool making or maintenance of car or airplane parts.

Plastic blasting media is currently offered from several distributors in Norway according to their product catalogues. No information is provided if this is for use outdoors or in closed units with recovery of blasting media. We have no information on volumes. It must be assumed that at least some plastic preening media is used in mobile missions on, for example, industrial sites or manufacture machinery where running the blasting as a sealed process is not an option. The general handling and collecting routines of sand blasting media in Norway is known to be sloppy, even if regulations prohibits dumping, see chapter 6.3.2.

Earlier estimates on the use of plastic blasting media are rare. In 1989, a study on sandblasting media used in the Oslo region produced by the Norwegian National Institute of Occupational Health mentioned that in the late 70's in the USA, plastic grit was then less than 1.1 % of volumes used[50]. But in Oslo around this time no such product was registered, only conventional mineral media and grit. We found no mention of Norwegian use of plastic blasting media in the recent and wide-ranging reports about paint related work offshore or in shipyards. Thus, if used, the volumes must be relatively limited in Norway even if often cited as a microplastic source internationally.

Hand wash for industries
While most modern microbead products are aimed at the beauty-market (e.g. peeling face wash), it becomes clear from reading the old US hand cleaner patent previously mentioned that it was intended for a very different use: hand cleaning for heavy dirt, oil and grease for workers in different industries, public and commercial enterprises. The soap was intended for use in " *the more than 100.000 cream type dispenser units made of rigid polyvinyl chloride in use today in industry*"(1972).

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[47] Gregory, M.R. (1996). Plastic 'scrubbers' in hand cleansers: a further (and minor) source for marine pollution identified. Marine Pollution Bulletin, 32, 867-871.
[48] Arthur, C. ,& Baker, J. (eds.) (2011). Proceedings of the Second Research Workshop on Microplastic Debris. November 5-6, 2010. NOAA Technical Memorandum NOS-OR&R-39.
[49] Miles, R., Clark, L., Ellicks, D., Hoch, R., Garrett, L., & Chambers, B. (2002). Plastic Media Blasting: The Paint Remover of Choice for the Air Force. Metal Finishing, July 2002, 14-17.
[50] Bye, E., & Gylseth, M. (1989). Sandblåsing - En kartlegging av blåsemidler i Oslo-regionen. Arbeidstilsynet. (Report, in Norwegian, about blasting materials).

According to the major Norwegian producer of soaps and cleaning products used in commercial and public enterprises, there are no plastic microbeads added to these products. We have found no information about microbeads in imported hand wash, so we assume use is limited.

Specialty chemicals with plastic microbeads
In oil and gas exploration (and other kinds of rock drilling), drilling fluids based on plastic microbeads have been used for a few decades[51], and in the last ten years, Teflon strengthened particles have been patented and marketed heavily for drilling purposes internationally. If these are used in Norway and regarded as green chemicals, the releases directly to the ocean are in tonnes. There are some recovery and waste collection of muds and drilling fluids, but the waste treatment process is not designed for, and gives no mention on, how to handle plastic particles, so this has clearly not been an issue[52].

According to a senior environmental advisor in the largest Norwegian oil company, there are many polymer types in use as drilling muds, but they are too small to be considered particles. Our sources are unsure about the use of microbeads like those reported internationally.

Other commercial uses of designed microplastics
The plastics and polymer industry has expanded greatly into many commercial fields, and is constantly looking for, testing and marketing new uses of polymer products. It is outside the scope and frame of this study to provide any full list of recent advances and applications for micro- or nano sized polymer particles in products, intermediates, speciality chemicals and chemical products on the world market, but some examples with special relevance in the Nordic and Norwegian industry and/or emission context are:

- Plastic beads for commercial Dishwashing ('Power granules') supposed to be used on ships. Supposed to be a closed system with no emissions.
- Rubber fragments (made from shredded car wheels) used as ingredient in artificial grass on sport fields. Supposed to be collected if spreading outside field.
- Medical applications of plastic beads or spheres in, for example, medicines (Ugelstad monobeads). Supposed to be very small volumes in more or less closed applications.
- Dust control liquids with polymers to be applied on roads, in open mines, in water treatment and more. Supposed to be water soluble polymers.

For many of these uses of plastic polymers, it is difficult to establish if the polymers are present as particles or in other forms, from publicly available information. This should be subject to further investigation as some potential uses mentioned are high volume and with direct emissions.

Use in chemicals: Registered uses of plastics in chemical products used in Norway
In the Norwegian chemical products registry[53], notification of the import and use of chemical products with toxic and/or other dangerous properties is mandatory. Most relevant plastics

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[51] Skalle, P., Backe, S.K., Kilaas, L., Dyrli, A.D., & Sveen, J. (1999). Microbeads as Lubricant in Drilling Muds Using a Modified Lubricity Tester. SPE 56562 Abstract to be presented at the 1999 SPE Annual Technical Conference and Exhibition held in Houston, Texas, 3–6 October 1999.
[52] Ystadnes, Lars, Statoil, Norway, personal communication, and personal observations.
[53] More information about the Product Registry http://www.miljodirektoratet.no/no/Tema/Kjemikalier/Produktregisteret/The_Product_Register/

and polymers are not expected to be registered, as we rarely find any mention or volume of polymer/plastic in data sheets (MSDS, TDS). Compounding this lack of required reporting, exact brand names, product types and mixtures are protected as sensitive industry information. Some information with examples on the use of plastics in chemical products has been made available from the Environment Agency for this study. These are registered as chemical products and it is assumed that the plastics are present in the product as evenly distributed particles. It is not known if these are for open or closed use, or intermediates. Some of the uses include paints, and would hence already be counted in other chapter of this report.

Annual total consumption (2013) of selected plastics in chemical products declared at the Norwegian Product Register[54]:

5 tonnes PTFE, divided among 30 product groups.
50 tonnes polyethylene, divided among 40 product groups.
29 tonnes Butadien-styren copolymer, mainly for glues, but also paint
18 tonnes polymetylmetakrylat, mainly in paint, but also glues

No information on pollution control is available for these uses.

Emission estimate of commercial use of plastic microbeads: *N.A. but as default value 100 tonnes*

Assuming as a default value, without any information, that plastic particle consumption registered as chemicals are less than half of all products actually used, our guess would be that commercial uses and emission of microplastic is in the order of 100 tonnes (see above) or above per year. That is slightly above the use in personal care products.

The estimate here for commercial products may contain some products which also have consumers as end-users.

This source group needs further investigation.

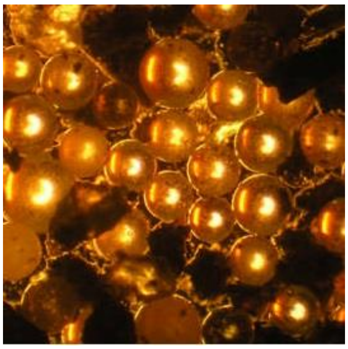
6.2. Unintentional spill in production and transport

6.2.1. Pellets loss from plastic factories and transport

Plastic pellets, often called nurdles and mermaid tears, are small pieces of plastic resin approximately the size of a split pea, about 20 mg each[55], and are found in many field studies of marine microlittering.[56] These are also the microplastic type often assigned to a single point source nearby[57], or to a general global source group: Pellets loss from the plastics

[54] Data extract communicated by personal communication from the Norwegian Environment Agency.
[55] Webpage: en.wikipedia.org/wiki/Plastic_particle_water_pollution
[56] For example: Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin, 62(12), 2588-2597.; Costa, M. F., do Sul, J. A. I., Silva-Cavalcanti, J. S., Araujo, M. C. B., Spengler, A., & Tourinho, P. S. (2010). On the importance of size of plastic fragments and pellets on the strandline: a snapshot of a Brazilian beach. Environmental Monitoring and Assessment, 168 (1-4), 299-304. ; Fotopoulou, K.N., & Karapanagioti, H.K. (2012). Surface properties of beached plastic pellets. Marine Environmental Research 81, 70-77. ; Llorca, M., Farré, M., Karapanagioti, H.K., & Barceló, D. (In press 2014). Levels and fate of perfluoroalkyl substances in beached plastic pellets and sediments collected from Greece. Marine Pollution Bulletin.
[57] For example: Colton, J. B., Knapp, F. D., & Burns, B. R. (1974). Plastic particles in surface waters of Northwestern Atlantic. Science, 185(4150), 491-497.; Fabbri, D., Tartari, D., & Trombini, C. (2000). Analysis of poly (vinyl chloride) and other polymers in sediments and suspended matter of a coastal lagoon by pyrolysis-gas chromatography-mass spectrometry. Analytica Chimica Acta 413, 3-11. ; Wilber, R. J. (1987). Plastic in the North - Atlantic. Oceanus, 30(3), 61-68.

manufacturing chain. There are thousands of plastic converters in the world that use these granules in their production[58]. Additionally, millions of smaller recycling plants are producing regranulate, a nurdle often grey or black[59]. Batches of nurdles or pellets might also contain finer plastic dust as contamination from raw material production or created during transport and transfer. This may entail dust, cracked pellets, mis-cuts and so called tails, worms, snake skins, ribbons, angel hair and so on[60]. During pre-production, scrap such as grindings, cuttings and other fragments might be created and accidently discharged [61].



Origin: Production spill
Number of sources: about 60 plastic converters Norway
Plastic types: PS, PE , PVC
Haz.additives: yes, f.ex HBCD
Particle size, mm: about 1 mm
Particle shape: spherical or discs
Specific gravity: depending on product, can have airbubbles adding buoyancy

Figure 6-3 Short facts about microplastics from production spill. Photo: Polystyrene pellets lost to the sea from a Norwegian factory.

According to the Global Plastics associations[62] this is still a significant microplastics source which they aim to reduce. Many plastics are sold in pellet form and these pellets are shipped through various means – in big bags, boxes, trucks, rail cars, barges – to companies that make products with these pellets. Throughout this process, pellets can be spilled into the environment.

Description of sector

At present there are above 60 plastics converters/manufacturing plants registered in Norway,[63] divided quite evenly between four sectors: boat building, construction materials, packaging materials and 'others'. Most of these should be regarded at potential historical point sources and present sites at risk of unintentional loss of plastic pellets or particles. Most of them are located at the seaside. These converters either import their raw material (mostly pellets or powder) from producers or compounders or buy the materials directly from a Norwegian raw material producer.

The total demand of plastic raw material in Norway is estimated 250.000 tonnes in 2013, based on *PlasticsEurope* annual surveys. In addition, about 10.000 tonnes of regranulate is produced in Norway and partly exported, while a similar amount is assumed to be imported.

In Norway *INEOS* is the largest raw material producer. At their plants in Bamble, *INEOS* has a capacity of 140.000 tonnes of PE and about 180.000 tonnes of PVC per annum. Most of the

[58] EuPC, webpage; There are 50.000 plastic converters only in Europe
[59] Recyclers often recycle plastic waste of different colors resulting in a grey regeranulate. Sometimes black color is added too, for example carbon black.
[60] Dhodapkar, S., Trottier, R., & Smith, B. (2009). Measuring Dust and Fines In Polymer Pellets. Cheical Engineering, September 2009, 24-29.
[61] Moore, C. J. (2008). Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environmental Research, 108(2), 131-139.
[62] The Global Plastics Associations. (2014). The Declaration of the Global Plastics Associations for Solutions on Marine Litter - progress report.
[63] Norwegian Environment Agency, personal communication and printout from industry database.

production is exported and transported by road/ferries. The pellets are packed in big bags or shipped in bulk, or in tanks. PVC raw material from *INEOS* is often shipped to Malmø in Sweden for compounding.

The PVC consumption of converters is estimated to be 100.000 tonnes in the Nordic region and just 25.000 tonnes in Norway . Key products in Norway are pipes and other building materials.

Brødrene Sunde in Ålesund on the west coast is both a leading PS raw material producer and producer of EPS products. The PS pellets are shipped in thick tight PE bags in octa-bins of 1.250 kg. Production figures are not available; the annual turnover is about 1, 8 billion NOK. Total annual production volumes of polystyrene in Norway (several producers) was estimated as 43.000 tonnes.

There are also some other industrial sites that might handle plastic raw materials, for example, in textile and paper production. Traditionally these industries are generally placed near waterways with high water consumption and significant emissions (e.g. from cleaning of equipment between batches, dust cleaning from production facilities). A range of modern paint and inks contain polymer particles or microspheres. If spilled during production they may reach the environment.

Emission factors

"On 24 July 2012, during the strongest storm in 13 years, 150 tonnes of pellets were knocked off a freighter in waters south of Hong Kong. The plastic raw material, pellets/nurdles, from the Chinese company Sinopec were, according to media sources, piled up, like snow, on beaches[64]. "

In addition to such severe accidents, the number of smaller incidents along the whole plastic value chain probably contributes even more to global plastic pellet pollution[65]. Such losses also very likely occur at the recyclers producing pellets and the producer consuming these regranulates.

Norwegian producers and recyclers say contemporary pellets losses and production spills are probably insignificant, but still possible. However, recent field studies in Nordic waters indicate there are both historical and still active point sources of what must be quite regular pellet losses from plastic factories in Norway and Sweden. One example is in a bay on the Norwegian west coast where academic scientists were investigating the biological uptake of the plastics flame retardant HBCD outside a polystyrene plant. By coincidence, they discovered that the sediment was full of polystyrene microbeads[66]. Another recent study on the Swedish west coast discovered highly elevated numbers of uniform microbeads in the sediment and water just next to a polyethene production plant[67].

The OECD has given an emission factor of 0,5% (5 gram released/kg handled) for transport losses of solid powders in general. This is a worst case scenario, based on USEPA studies in

[64] An international example of accident, webpage: en.wikipedia.org/wiki/Plastic_particle_water_pollution
[65] Probably, more such accidents can be documented from Lloyds/ Insurance companies and different webpages of NGOs, inclusive www.nurdle.org.
[66] Haukaas, M., Ruus, A., Hylland, K., Berge, J.A., & Mariussen, E. (2010). BIOAVAILABILITY OF HEXABROMOCYCLODODECANE TO THE POLYCHAETE HEDISTE DIVERSICOLOR: EXPOSURE THROUGH SEDIMENT AND FOOD FROM A CONTAMINATED FJORD. Environmental Toxicology and Chemistry,29 (8), 1709–1715.
[67] Norén, F. (2009). Small plastic particles in coastal Swedish waters. Report. KIMO Sweden.

the transport sector of what remains or gets spills from transferring material from different transport containers[68] inside or outside the production line. In addition, there would certainly be spills from the production line itself through the effluent system and even past best available control and treatment measures. We have extracted an emission factor for this from real data from a Norwegian polystyrene plant during the last decade: 0.4 grams per kg produced[69].

Emission estimate pellets and plastic production spill: totally 450 tonnes

Based on the USEPA emission factor of 5gram/kg handled from transport, and a Norwegian annual plastic transport volume of ≈500.000 tonnes (import for demand plus production for export, no exact total balance available), this would give a potential spill of plastic fines of ≈2.500 tonnes without any control measures. There is no exact information on the effect of spill control measures on the transferring processes, but we expect these to be in place in a large proportion of the industrial sites, hence we are adjusting the estimate down to 250 tonnes.

From the same production volume and an emission factor for production of 0,4 gram/kg produced, ≈200 tonnes are expected to be spilled per year directly from Norwegian production sites. Of this, ≈20 tonnes would be polystyrene and over ≈40 tonnes would be polyethylene and polyvinylchloride, respectively.

Control measures and trends

The industry has started a voluntary initiative, *'Clean Sweep',* where manuals and tools designed to improve good housekeeping practices have been made broadly available to companies that handles plastic pellets, including resin producers, transporters, bulk terminal operators and plastics processors. The plastic Industry in several countries, including Denmark, has committed themselves to *Clean Sweep*[70].

The OECD states that any treatment process applied on air or water within industries, and recycling of captured plastic materials within the process, is usually removing about 90-95% of errant particles. There are strict emission controls in Norway on large volume industries handling risky materials like plastic additives, and transport loss is mentioned in the regulations for each factory.

Sampling of microplastic emissions and discharges from the plastic factories, and recipient environments, such as sediments and soils, would be needed to verify the rates of discharges and further need for control measures.

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[68] USEPA as referred to in OECD (2009). EMISSION SCENARIO DOCUMENT ON ADHESIVE FORMULATION. Page 153: "The EPA/OPPT Dust Emissions from Transferring Solids Model estimates that 0.5% of the solid powder transferred may be released from dust generation". This model is based on 13 sources, including site visit reports, including plastics manufacturing.

[69] Documented annual HBCD emission in pellets to effluent, one factory: 12kg. HBCD concentration in polystyrene pellets: 0,5-1%. Estimated Plastic pellets emission, with HBCD: 1200-2400kg. Total plastic production 6000 tonnes.= 0,4 kg pellet spill per ton. Sources: correspondence between factory and Norwegian Environment Agency, as well as Norwegian Environment Agency/SFT (2003). Bruken av bromerte flammehemmere i produkter. Materialstrømsanalyse. (Material flow analysis Brominated Flame Retardants in products. Report in Norwegian). TA-1947.

[70] Fabiansen, Helle, Plastindustrien, Denmark, personal communication and presentation in Oslo on 7 November 2014.

6.3. Microplastic as a by-product / dust emission

6.3.1. Maritime coatings: shipyards, marinas and boatyards

In several studies from different locations around the world (Sweden[71], Korea[72], UK[73], Italy[74] and Portugal[75]) with ship maintenance activities nearby, microplastic particles have turned up in high numbers, identified as plastic types known to be common in maritime paints, and with the same colours as nearby vessels at work. Much focus has earlier been on the emissions of heavy metals and persistent organic pollutants from such sites[76], in particular from abrasive blasting activities. Few Norwegian shipyards have installed any efficient effluent treatment such as those in use at shipyards in some other countries[77].

Origin: maritime paint
Number of sources: 70-90 shipyards in Norway
Plastic types: epoxy, polyurethane and others
Haz.additives: yes.
Particle size, mm: variable.
Particle shape: tiny flakes and irregular pieces
Specific gravity: depending on product . Most will sink. The smallest fraction can float on surface film alone.

Figure 6-4 Repair yards emit polymer paint particles directly to the sea

Sector description Shipyards

Modern maritime coating systems are all based on some plastic polymer chemistry, according to the OECD[78]: *"Anticorrosive paints include vinyl, lacquer, urethane, or epoxy-based coating systems. Typical primers used on boats are one- and two-pack epoxy coatings. Typical finishes include one and two-pack polyurethanes. Varnishes used on boats are often also polyurethane based."* A general trend in the marine paints sector the last decade has been towards paint with higher solid content (less dangerous solvents), and a movement away from the polyurethane paints over to epoxy paint and even newer paint formulations with a range of polymers. For antifouling

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[71] Norén, F., Norén, K. & Magnusson, K. (2014). Marint mikroskopiskt skräp. Undersökning längs svenska västkusten 2013 & 2014. (Report in Swedish). IVL. Rapport 2014:52. Länsstyrelsen i Västra Götalands län, Vattenvårdsenheten.
[72] Song, Y.K., Hong, S.H., Jang, M., Kang, J., Kwon, O.Y., Han, G.M., & Shim, W.J. (2014). Large Accumulation of Micro-sized Synthetic Polymer Particles in the Sea Surface Microlayer. Environmental Science & Technology, 48, 9014−9021.
[73] Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D., & Russell, A. E. (2004). Lost at sea: Where is all the plastic? Science, 304(5672), 838-838.
[74] Vianello, A., Boldrin, A., Guerriero P., Moschino V., Rella, R., Sturaro, A., & Da Rosb, L. (2013). Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification. Estuarine, Coastal and Shelf Science, 130, 54-61.
[75] Frias, J.P.G.L., Otero, V., & Sobral, P. (2014). Evidence of microplastics in samples of zooplankton from Portuguese coastal waters. Marine Environmental Research, 95, 89-95.
[76] Miljøverndepartementet. (2010). Et Norge uten miljøgifter (NOU 2010:9). (Report, in Norwegian).
[77] Norsk Industri. (2012). Beste praksis for miljøarbeid i skipsverft – utslipp og avfall. (Report, in Norwegian)
[78] OECD. (2009). OECD SERIES ON EMISSION SCENARIO DOCUMENTS. Number 22. EMISSION SCENARIO DOCUMENTS ON COATING INDUSTRY (Paints, Laquers and Varnishes).

paints, several polymers are used, but according to the paint industry they are mostly present in non-particulate forms.

The marine paint market in the EU (2001, excluding antifouling paints), was above 110.000 tonnes[79]. Norway presumably has a larger share of this than the per capita average because of large maritime sector. Jotun, the Norwegian international producer of maritime paints who claim to cover 20% of the world market had 6% market share (by value) in Scandinavia, with 20% in the rest of Europe[80]. Assuming that Norway constitutes roughly a third of the Scandinavian market, if Jotun sales in Europe are representative , about 8% of all maritime paints in Europe are consumed in Norway. A typical marine paint contains above 50% solids, of which about half is the polymer binder/resin. Globally, about a quarter of the maritime paint market is for leisure boats, a small fraction of paint for containers, and the rest for ships and offshore installations[81].

Emission factors Shipyards

According to Norwegian paint industry sources[82] it is reasonable to assume that modern epoxy based maritime paints emit particles fulfilling the microplastic definition when they are removed by abrasive blasting, and also during spill when applying.

During paint removal by abrasive blasting on ships, a rule- of –thumb is that about 0.5kg paint material dust is created per m^2 blasted. Common blasting techniques are sand-, plastic-, air- or hydro-blasting. If sandblasting media is used, up to 0.5% will typically be contaminated by the removed paint material. Note that the normal dry film thickness of marine paints is in the range of microplastic, up to a few mm, and when pressure blasted it comes off in fines. Regarding spill during paint application, the industry norm is about 30%. This is usually fine drops that drift away in the air when spray-painting. When these solidify they would be in the microplastic size range.[83]

The OECD (2009) report already cited has developed emission factors for maritime paints by advice from experts within the paints industry. According to these sources, it can be assumed that about 6% of the solid coating content is spilled directly to the sea during the lifetime of such a maritime coating product. About 1.8% is spilled during painting, 1% from weathering, and 3.2% during maintenance and abrasive blasting. In addition 5% is expected spread to soil. We regard this as an underestimate for Norwegian shipyards with no proper effluent treatment, here we would expect only large paint fragments removed to be retained in the dock and disposed of as hazardous waste, while all smaller fragments to be washed out. With no knowledge about the share of this fraction we suggest a worst case emission factor of at least double the OECD factor.

Earlier estimates on volumes discharged

No earlier national estimates on polymer spills through maritime paints have been found, and no data have been made available for this study from the Norwegian paint sector. Nordic and Norwegian sources have, however, earlier estimated 20-40% paint loss during painting of ships. If this is done outdoors or while the ship is at sea (not docked) a large proportion of this would certainly get into the sea. In 1990 it was estimated that the total loss of paint

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79 OECD. (2009).
80 Jotun, annual report, retrieved from web: http://cdn.jotun.com/images/2012-jotun-group-report_tcm60-1364.pdf
81 Paint Research Association note, retrieved from web: http://www2.pra-world.com/download/pdf/GICM_Sampler.pdf
82 Kvernstuen, Johnny, Jotun Marine Paint, Norway, Personal communication.
83 Nordisk ministerråd (1995). Reduksjon av utslipp fra skipsverft. (Report, in Norwegian). Tema Nord 1995:609.

during application at the Norwegian coastal fleet alone was 150.000 litres, and that the potential paint spill from painting a cruise ship alone would be about 50.000 liters.

<u>Emission estimate professional maritime paints: 330 tonnes</u>

Based on annual sales volumes of maritime paints in Europe, a rough estimate for Norwegian consumption is 8000 tonnes, of which 75% is for professional use on large vessels. We can thus estimate microplastic discharges to the sea from coatings on ships during this paint's lifetime. (OECD emission factor 11% and the polymer binder content 25%). This provides annual emissions in the range of 165 tonnes. We regard the OECD emission factor as most probably an underestimate for the Norwegian shipyards, and hence suspect discharges to sea and soil of about double the OECD factor: 330 tonnes per year. A large part of this would be discharged from shipyards. A fraction of it might go to soil, the rest to sea.

Control measures and trends

Only a few shipyards in Norway have water treatment systems, but most of them would collect some coarse paint dust as hazardous waste. It is stated by the Industry association report already cited that the finer paint particles are, to a large extent flushed directly into the sea, and that the industry don't yet find it costworthy investing in more efficient water treatment or dust collecting systems.

Boatyards for recreational vessels

Figure 6-5. Photo: Almost all removed paint from boatyards are spilled to the sea or shore

In addition to shipyard emissions, there are significant paint spills at all marinas that have commercial or do-it-yourself maintenance yards for recreational vessels, or when boat owners do paint maintenance at their private property or onshore.

Sector description marinas and boat maintenance yards

In a recent large questionnaire poll among Norwegian boat owners, important details about maintenance routines was revealed[84]: In Norway only 10% of the boat owners give their boat to a marina or shipyard for maintenance. Sixty percent say they do all maintenance work by themselves, while the rest do as much as they can. We believe there is thus a low potential for professional treatment of water or air emissions from recreational boat maintenance. In

[84] Kongelig Norsk Båtforbund (2012). Båtlivsundersøkelsen 2012. Fritidsbåtlivet i Norge. Report (in Norwegian, about recreational boating habits in Norway).

Norway, paint chips and washing water effluents at these sites are, in all but a few cases, still directed directly to the nearby sea[85]; only 10% of the boat owners say they have access to any collection system for paint dusts. There are about 750.000 recreational vessels in Norway. Assuming that roughly half of these are in use and kept at some kind of maintenance yard, with ≈200 boats in an average marina, there are ≈2.000 boat maintenance hot spots in Norway. The rest of maintenance work is spread everywhere along the populated coast and in garages and gardens.

Emission factors

Paint industry sources confirm that similar to commercial maritime paints, primers and some top coatings on recreational vessels are likely to give away microplastic dust when rubbed, abrasive blasted, washed or repainted. Plastic dust from rubbing down the surface of glassfiber resin hulls during repair would certainly add to emissions, but these are not included in this report because we have no knowledge about the volume of such repair work. We also regard it[86] as minimal compared to paintwork and work on surface coating.

The OECD has stated that no emission factor could be established on emissions from recreational use of maritime paints, because of lack of data. Based on recent Norwegian findings already mentioned, less than 10% of boat owners use any paint dust collection or control system, thus expected spill of paints over time is likely to be >90% of all paints used.

Earlier estimates on paint spills from recreational boat maintenance yards

Studies for example in Sweden[87], Norway and the UK[88] have clearly established the high flows of paint and antifouling particles from boat maintenance yards, but none of them measured microplastics specifically. Most focus has been on heavy metals and similar toxic chemicals. These examples illustrate the high paint turnover and spills at such yards: Eklund *et al.*[89] calculated from soil concentrations of heavy metals found at a boatyard with 200 boats, a total accumulated amount of 80 tonnes Pb, Cu and Zn (worst case) left in the soil.

Emissions estimate from recreational boatyards: 400 tonnes

If about 25% of the maritime paints (antifouling not included) sold in Norway is used on leisure boats, we would expect this to be about 2.000 tonnes per year. Again assuming a polymer content of about 25% by weight, the overall discharge of microplastic from leisure boats in Norway as a worst case would be in the range of 400 tonnes per year assuming that almost all is spilled to soil or sea. Or 0.5 kg per annum, per boat owner.

Source control measures and trends

In Norway, there is slowly increasing attention for the need of having some kind of collection and treatment system of paint dust spills. There are 5 registered Blue Flag certified marinas in Norway, and 34 marinas engaged so far in the Ren Marina (Clean Marina) initiative. In Sweden, quite a few marinas have water treatment with particle filtering. Also vacuum

[85] NGI (2010). Prosjekt småbåthavner - utredning av miljøfarlige utslipp som følge av drift. Kartlegging av forurensing i utvalgte småbåthavner i Norge. (Report, in Norwegian), Norwegian Environment Agency, TA-2751/2010.

[86] Personal observation from harbours and boat maintenance yards.

[87] Eklund, B., & Eklund, D. (2014). Pleasure Boatyard Soils are Often Highly Contaminated. Environmental Management, 53, 930–946.

[88] Turner, A.(2013). Metal contamination of soils, sediments and dusts in the vicinity of marine leisure boat maintenance facilities. Journal of Soils and Sediments, 13, 1052–1056.

[89] Eklund, B., Johansson, L., & Ytreberg, E. (2014). Contamination of a boatyard for maintenance of pleasure boats. Journal of Soils and Sediments, 14, 955-967.

cleaners connected to paint removal activities are regarded as an efficient pollution control measure.

If we assume that the paint spill is divided 50:50 between sea and soil at the boat yards like the OECD do for shipyards, several thousand tonnes of microplastics might be accumulated in the ground. Sampling of microplastic particle flow and historical stores in sediments and soil at marinas and shipyards thus seems like an appropriate topic for follow up studies.

6.3.2. Building surface maintenance

In addition to the emissions of plastic dusts at shipyards and marinas, there are important point sources of polymer dust also when cleaning plastic-treated surfaces on buildings and constructions elsewhere[90]. Both concrete, metals, wood and other materials may have a coating based on polymers, or can even be directly covered by plastic.


Slik så det ut da Naturvernforbundet var på befaring i området rundt Hakavik kraftstasjon sommeren 2010. Støvet på liljekonvallen viste seg å inneholde miljøgiften PAH.

FOTO: NORGES NATURVERNFORBUND

Dumpet miljøgift i naturen

Tonnevis med giftige malingrester og gruveslagg har i årevis blitt ulovlig dumpet rett i naturen rundt landets små og store kraftverk. Ingen har oversikt over omfanget av problemet.

Stine Barstad
Publisert: 22.feb. 2011 22:09 Oppdatert: 12.okt. 2011 21:47

Anbefal Bli den første av dine venner til å anbefale dette.

Sandblåsning:

Cirka hvert 20-30 år må kraftselskapene pusse opp rørene som leder vann til kraftstasjonene. Disse sandblåses, før ny

Figure 6-6 Facsimile from the paper Aftenposten 2011 on illegal dumping of sandblasting waste.

Sector description

The market for protective coatings in Europe is [91] about 300.000 tonnes per year . We assume that the Norwegian share is roughly the per capita average and that this has stayed fairly constant[92]. That is 3.300 tonnes. Further, the annual per capita use of so called decorative paints for exterior surfaces in Europe, for example on brick, concrete or wood buildings, is 3.5 kg. For Norway this gives about 17.500 tonnes.

Emission factors

Few studies seems to have been done on the plastic particle emissions in this sector, but there are examples on general paint dust emissions from works indicating the considerable microplastic point sources they might be. Furthermore, there are yet no firm routines established among all contractors using some kind of abrasive blasting. Dust from paint

[90] For example: Jartun, M., & Pettersen, A. (2010). Contaminants in urban runoff to Norwegian fjords. Journal of Soils and Sediments, 10, 155–161. ; Eidem, B. (2012). Spredning av forurensning fra land til havnebasseng i Stavanger havn. Masters thesis (In norwegian). Norges teknisk-naturvitenskapelige universitet.
[91] OECD (2009). as referred to earlier.
[92] Norway population today: 5 million, EU 2001 when paint estimate is from: 450 million.

application, rehabilitation and maintenance work on other painted metal constructions: bridges, buildings, pipelines, offshore rigs or drill ships therefore is likely to be spilled.

Based on the OECD emission factor of 6.4% for removal and fugitive loss of paint particles to soil and water during maintenance and abrasive blasting on ships, we find it reasonable applying this to different other constructions and paint types of the category "protective coatings". There are several studies showing that abrasive blasting in general can emit a few percent of the paint, not only from ships.

In addition, the OECD estimates for outdoor decorative coating (normal paint for house exterior) about 1. 5% loss of the solid paint to sewer during application, with no losses during maintenance (they assume all decorative paint being disposed of through waste system) . This seems like an underestimate. Both professional and do-it-yourself maintenance on outdoor house paints clearly involves rubbing or pressure blasting with spill potential. Hence we will apply an emission factor of 5% to this with no other data available.

The rest of the removed paint, more than 90% of the originally applied solids, is often regarded as "disposed of" as waste (in a closed waste loop for hazardous or normal waste).Our experience is contrary to this. In a great number of rehabilitation works up to now, unfortunately not only the expected loss fraction, but also most of the "disposed of" fraction, is directly discharged to the sea or soil. Below are some real life examples:

Example 1: A road bridge crossing the water[93]. The total surface area of the bridge covered with paint is 11.000 m^2. Assuming a 2 mm thick layer of paint, a total of 22.000 litres of paint solids would have been added to the bridge surface. It was presumably dumped in the fjord during renovation and sandblasting some ten years ago, because the seabed locally below the bridge is very contaminated by PCB, a usual content and hence tracer of old paints used on metal construction. If polymer binder is 50% of this solid content, and at a specific gravity of 1.2, about **13 tonnes** of particulate polymer, would have been emitted. In this case the paint was presumably chlorinated rubber with PCB as a plasticiser.

Example 2: Oil drill unit maintained while on sea[94]. A total renovation of the above waterline painted surfaces was done while the 250 meter long vessel was staying on the water, dockside. All removed paint was spilled; nothing collected or declared as hazardous waste. Assuming a blasted surface area of 2.000m^2 (patchy removal only), and applied 8.000ltr of new topcoat with 30% of this spilled, about **2 tonnes** of polymer particles in the paint, much of it in micrometre range, would have been emitted. In this case the new topcoat contained polysiloxanes.

Example 3: Power station renovations[95]. Renovations and sandblasting of old hydropower stations and hydropower water pipelines have emitted large amount of sandblasting media contaminated with the removed paint in the terrain many places in Norway. As the hydropower stations are often located near waterways, there is potential for direct spill to rivers and the sea. In a particular case the coating contained PCBs, and paint particles were

[93] This example adapted from Jartun, M., Ottesen, R.T., Steinnes, E., Volden, T. (2009). Painted surfaces—important sources of polychlorinated biphenyls (PCBs) contamination to the urban and marine environment. Environmental Pollutio, 157, 295–302.
[94] This example based on official correspondence between an oil service base and the local representative of the Norwegian Environment Agency (Fylkesmannens miljøvernavdeling).
[95] Based on a mapping done by Norwegian Society for the Conservation of Nature by written communication with all the largest hydropower companies in Norway, made available for this study.

flushed into the fjord where cod ate it and got heavily contaminated. Paint particles were found inside the cod stomachs.

When estimating paint spills and macroplastic spills from this sector, some illegal dumping of waste should also be included among the regular spills.

Emission construction maintenance work, regular: 270 tonnes

Expected paint spill during regular maintenance work on protective coatings (non-marine) is expected to be 6.4% of the annual sale volume of 3300 tonnes, of which 25% by weight could be polymer = 53 tonnes. To this we have to add spill from outdoor maintenance of decorative exterior coating (5% of 17.500 tonnes X 25%), about 220 tonnes. Some of this would be emitted to public sewer, but most is expected to end up in the terrain or directly in the sea if a seaside location.

Emission construction maintenance work, irregular dumping: 100 tonnes

This is just an estimate, based on the examples above; assuming that about 10 such incidents happen every year and/or the general loss of paint is larger than the maritime industry standard.

6.3.3. Commercial cleaning of synthetic fibers: textiles

Effluent from commercial laundries and cleaning workshops set up in public service or companies will, without any filtering of the effluent water or air, be point sources of microplastic fibers just like home laundries.

Sector description

Norway has about 300 commercial laundries and textile service companies[96]. For dry cleaning there are about 200 dry cleaning machines in Norway. There has been little mapping of their Norwegian effluents to water, but some investigations of their waste streams[97] and air emissions due to the solvents used. Dry cleaning (with solvents, no water) is an important part of the services offered. As opposed to water based cleaning, dry cleaning is a more or less closed process. Modern machines are completely sealed, while slightly older machines have some emissions of solvents and dust to air. Sludge containing used solvents, dirt and textile dust is commonly removed from each machine every week, ending up as waste. Only about one third of this textile dust containing solvent waste in Norway in the last ten years is registered as delivered for proper treatment by thermal destruction, about ten tonnes per year. The rest has an unknown destiny.

We have no data on the amount of laundry washed in total in Norwegian commercial laundries. However, an in-depth study on the laundry sector in Finland showed that about 10% of the annual total of textiles washed is done so in commercial or public laundry as distinguished from private households[98].

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[96] The Federation of Norwegian Industries (2014). Webpage, retrieved 7.11.14 http://www.norskindustri.no/Bransjer/renseri-og-vaskeri/

[97] Statens forurensningstilsyn (2009). Kartlegging av tetrakloreten (”PER”) i avfallsstrømmen fra renseribransjen. (Report, in Norwegian). Rapport TA-2584/2009. Norway.

[98] Aalto, K. (2003). Who washes the laundry in Finland? Textile care in households and use of textile care services. English summary for the National Consumer Research Centre. Publication 11:2003. Finland.

Emission factors
For emissions of microplastic fibers from commercial laundry, it is probably reasonable to use the same emission factors per kg fabric washed as for private laundry (see elaborated in the following chapter, 6.4.1). By inspecting the discharge permits of a few large laundries we find there are expectations from the Pollution Authority that no dangerous pollutants are discharged, and that there should be some fiber trap on the effluent. But recent inspection reports show that the awareness and compliance to these regulations are low and we find no mention of active filtering of the effluent, or how efficient such filters are.

Emission estimate commercial laundry: about 100 tonnes

While detailed Norwegian data are not readily available, it is possible to do a rough estimation based on the 1:9 relationship from Finland. We assume as a simplification that textile wear across all wash processes (dry wash, water wash, hot or cold) are the same. Calculating Norwegian household laundry emissions to about 1000 tonnes in next chapter, this gives public laundry emissions of possibly 110 tonnes, of which a small fraction (less than 10 tonnes) according to public waste statistics is delivered as solvent waste and destructed and hence can be subtracted.

6.4. Emissions from wear and tear of plastic products during normal use.

6.4.1. Households, dust and laundry

There are other sources of microplastics from the households than the ones you can put a "microplastic" tag on. Actually, synthetic polymers are present in products and materials almost everywhere in households and the question is just where there are any significant emission rates of particles. Here we have to go outside the marine biology literature, for example to indoor air quality studies[99] [100] and studies about chemicals in household dust[101], in addition to studies on effluent from laundry and emissions via air conditioners. The fact is that abrasion and weathering of all kinds of plastic materials is well documented to contribute to household dust. Plastic fibers are among the most common constituents in indoor dust[102] [103].

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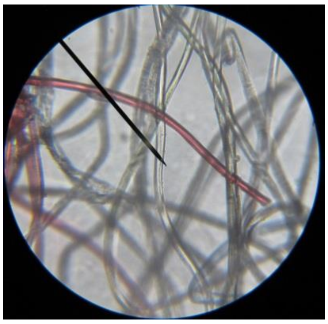
[99] Edwards, R.D., U, Edward J. Yurkow & Lioy, P.J. (1998). Seasonal deposition of housedusts onto household surfaces. The Science of the Total Environment, 224, 69-80.
[100] Morawska, L., & Salthammer, T. (2003). Indoor Environment Airborne Particles and Settled Dust. WILEY-VCH Verlag GmbH & Co. KGaA.
[101] For example: Webster, TF., Harrad, S.,Millette, J.R., Holbrook, R.D., Davis, J.M., Stapleton, H.M., Allen, J.G.,McClean, M.D., Ibarra, C., Abdallah, M.A-E., & Covaci, A. (2009). Identifying transfer mechanisms and sources of decabromodiphenyl ether (BDE 209) in indoor environments using environmental forensic microscopy. Environmental Science &Technology;43,3067–72. ; Wagner, J., Ghosal, S. Whitehead, T. & Metayer, C. (2013). Morphology, spatial distribution, and concentration of flame retardants in consumer products and environmental dusts using scanning electron microscopy and Raman micro-spectroscopy.Environment International, 59, 16–26.
[102] Gyntelberg, F., Suadicani, P., Nielsen, J.W., Skov, P., Valbjørn, O., Nielsen, P.A., Schneider, T., Jørgensen, O., Wolkoff, P., Wilkins, C.K., Gravesen, S., & Norn, S.(1994). Dust and the Sick Building syndrome. Indoor Air, 4, 223-238.
[103] Macher, J.M. (2001). Review of Methods to Collect Settled Dust and Isolate Culturable Microorganisms.Indoor Air, 11, 99–110.



Origin: Household and laundry dust
Number of sources: every household
Plastic types: Polyamide, Polystyrene, Acrylic
Haz.additives: yes.
Particle size, mm: Paint binder 0.01-0.02
Textile fiber lint: 0.01-0.1
Particle shape: fibers, tiny flakes, irregular pieces
Specific gravity: depending on product .

Figure 6-7 Short facts about microplastics from household and laundry dust. Photo: plastic fibers shed from a synthetic textile (polar fleece), from microscope.

Sector description

More than half of textiles used are now plastic polymer based: The world synthetic fiber consumption was 55 million tonnes in 2013 out of a total consumption of 90 million tonnes fibers[104].

Modern water based emulsion paints commonly used indoors are according to the OECD (2009)[105] "manufactured using a variety of polymeric resins such as styrene butadiene copolymers, polyvinyl acetate, acrylics, alkyds, and polystyrene." In products, these plastics are present as micrometre sized particles, after application they merge to create a more or less continuous polymer film after drying. When abraded, microplastic particles will be the result.

Synthetic clothing, curtains, furniture and carpet are shedding fibers every day, the old interior paint on the wall gives away flakes and chips, mattresses discard polyurethane particles, and even electronics might give away some plastic dust[106][107][108]. Such dust might very well end up in the drain. Consider, for example, the cleaning process for the air conditioner filter and the wet cleaning of floors and dusty surfaces. In addition, stuck in your clothes are also parts of house dust, which during laundry will be washed off together with shed fibers. Some of it is discharged as plastic fibers and particles to the sewer, while some re-enters the house from indoor drying of clothes and electrical driers.

Emission factors

The amounts of microplastic particles emitted from a household will of course vary greatly depending on materials used for construction and their durability, climate and living habits, to name a few varients. We have not found any studies specifically on the amounts or variability of plastic particles generated in Norwegian households. Most studies in this broad area have focussed on chemical contaminants alone, or just general particle loads[109]. For

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[104] According to Nova Institute, personal communication, based on publication The Fiber Year 2013.
[105] As cited earlier.
[106] Marklund, A., Andersson, B., & Haglund, P. (2003). Screening of organophosphorus compounds and their distribution in various indoor environments.Chemosphere, 53, 1137–1146.
[107]Rauert, C., Harrada, S., Suzuki, G., Takigami, H., Uchida, N., & Takatab, K. (2014). Test chamber and forensic microscopy investigation of the transfer of brominated flame retardants into indoor dust via abrasion of source materials. Science of the Total Environment, 493, 639-648.
[108] Brandsma, S., de Boer, J., van Velzen, M.J.M., Leonards P.E.G (In press, 2014). Organophosphorus flame retardants (PFRs) and plasticizers in house and car dust and the influence of electronic equipment. Chemosphere.
[109] For example a recent large Norwegian study: Cequier,E., Ionas, A.C., Covaci, A., Marcé, R.M., Becher, G., & Thomsen, C. (2014). Occurrence of a Broad Range of Legacy and Emerging Flame Retardants in Indoor Environments in Norway Environmental Science & Technology, 48, 6827−6835.

estimating the emissions of plastic dust particles from the households, two significant pathways are documented internationally, to some extent:

1) Fiber emissions from laundry: A UK study on microplastic sources[110] found that more than 1.900 plastic fibers (polystyrene) (or about 280 mg[111]) can, worst case, be shed from a textile item of 0.2kg during laundry wash, while the average number of fibers in the laundry machine effluent was about 200 per litre (or 30 mg/ltr). Similarly, a Dutch study reported that 260 mg fibers were released from a single 660 g polyester garment/washing[112], from exploratory tests. Also studies on incoming water to sewage treatment plants have found high numbers of synthetic fibers, e.g. a recent Swedish study relevant to Norwegian conditions reports about 10 synthetic fibers per litre. Assuming an average per capita water discharge of 400 litres to effluent per day in Sweden, this would yield about 4.000 fibers per day per capita (or 0.6 grams). This would include laundry discharges, but also other sources upstream.

2) Wet cleaning of settled indoor dust. There are some indications on the relative amounts of plastics in the indoor dust. For example, synthetic fibers were found to constitute 1-5% of household dust, and building material debris/acrylic plastic flakes 15-40% by volume in a single Boston home[113]. Similarly, high amounts of organic microparticles believed to be from paint and textiles in several studies of indoor air have been documented, this fraction often constituting several tens of percent of total indoor dust[114]. There also exist measurements on overall dust production in homes, as deposited per m^2 per year. These range from 1-8 grams, about 2 grams cited as the average from German and Finnish studies[115][116]. We would expect Norway to be at the upper end of the scale as people spend much time indoors, and often have to dry the laundry indoor (the drying room/area is often a significant source of textile fibers[117]). Hence 1-2 grams of microplastics, of this mainly textile fibers, settling per m^2 per year in a Norwegian household hence seems a reasonable factor[118].

An even more diffuse pathway of such household microplastics to the sea could be via air. It is shown for some plastic particle bound contaminants that indoor air via active ventilation is

[110] Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011). Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. Environmental Science & Technology, 45(21), 9175-9179.
[111] A commonly used measure of textile fiber weight is the term decitex (dtex), which for polyester and nylon fibers used in clothing typically would be about 300grams/10.000meter or less. Hence the weight of a 5 mm textile fiber would be 0.15 mg.
[112] Dubaish, F., & Liebezeit, G. (2013). Suspended Microplastics and Black Carbon Particles in the Jade System, Southern North Sea. Water, Air, & Soil Pollution, 224, 1352.
[113] Webster, T.F., Harrad, S., Millette, J.R., Holbrook, R.D., Davis, J.M., Stapleton, H.M., Allen, J.G., McClean, M.D., Ibarra, C., Abdallah, M.A-E., & Covaci, A. (2009). Identifying transfer mechanisms and sources of decabromodiphenyl ether (BDE 209) in indoor environments using environmental forensic microscopy. Environmental Science & Technology, 43, 3067–3072.
[114] See for example: Viana, M., Rivas, I., Querol, X., Alastuey, A., Sunyer, J., Álvarez-Pedrerol, M., Bouso, L. & Sioutas, C. (2014). Indoor/outdoor relationships and mass closure of quasi-ultrafine, accumulation and coarse particles in Barcelona schools. Atmospheric Chemistry and Physics , 14, 4459–4472. ; Maskey, S., Kang, T., Jung, H., & Ro C. (2011). Single-particle characterization of indoor aerosol particles collected at an underground shopping area in Seoul, Korea. Indoor Air, 21:, 12–24.
[115] Schneider, T. (2008). Dust and fibers as a cause of indoor environment problems. Scandinavian Journal of Work, Environment & Health 2008 pg. 10.
[116] Edwards, R.D., Edward, U., Yurkow, J., & Lioy, P.J. (1998). Seasonal deposition of housedusts onto household surfaces. The Science of the Total Environment, 224, 69-80.
[117] Personal observation. The drying of washed clothes releases fibers shed during the laundry process but not completely washed out.
[118] Exploratory sampling done by the authors comparing the rate of shed textile fibers settling to indoor surfaces (vacumed daily in a month) with shedding of fibers during laundry (filtered from laundry effluent water at daily wash) indicates the relative amounts would be of the same order. In our test house amounts of fiber, by weight, in these two fractions was almost equal.

a significant source to outdoor air[119]. The fraction of household dust emitted to outdoor air from a well-ventilated house is expected to be in the range 10- 15% of the total dust produced. Mostly the fine fraction particles (e.g. airborne particles of a few micrometres) would be emitted via air and could travel long distances in turbulent outdoor air.

Earlier international estimates
The Nova Institute has, during presentations about microplastic sources, made a basic assumption of a 1% loss of all synthetic fibers produced to the oceans, this emission equals 550.000 tonnes globally per year, or about 0,08 kg/ capita in the world.

Emission estimate laundry textiles: 600 tonnes.

To estimate the synthetic fiber discharges by laundry we have data on Norwegian laundry habits: about 70 wash cycles/ capita/year, of about 4 kg laundry and 60 litre effluent[120]. This equates to average Norwegian washes of 280 kg clothes annually with a water discharge from laundry machine of 4.200 litre. We assume that about half the textiles in Norwegian laundries are synthetic[121] By using the emission factors from the Dutch and UK study respectively the annual emissions of microplastic fibers from laundry varies between about 276 tonnes (Dutch: 280/0.66X260mgX5 million/2) to 315 tonnes (UK: 30mgX 4200X5 million/2). A worst case estimate based on the highest fiber counts per item in the UK study and a fiber weight of dtex 300 would be 980 tonnes (280/0.2X280mg/5 million/2). We think about 600 tonnes is a more realistic guess, combining the three estimates. This is 0.12 kg per capita per year.

Emission estimate indoor dust: 450 tonnes.

There are about 1.4 million households in Norway on an average square meter living area of 140m^2, giving a total of 210 million m^2. By using dust deposition rates from literature, and assuming from these that 2 grams microplastics per m^2/year is a reasonable estimate, microplastics settling on floors and surfaces in Norwegian households could be above 400 tonnes per year (0.08kg per capita per year). In addition some tens of tonnes would be emitted to the outdoors via air.

The estimates above on potential microplastic fibers released from laundry with addition of a fraction from wet floor wash (dust cleaning) and other indoor dust sources to sewer seem to be supported by the Swedish studies on number of fibers entering sewage plants. For Norway it would amount to roughly 1.000 tonnes (0.6g/capita/dayX5millionX365) assuming an average fiber weight (dtex) of 300g/10.000m.

Control measures and trends
The use of plastic based textiles, paints and materials is increasing[122]. There are no filters on

[119] Bjørklund, J.A., Thuresson, K., Cousins, A.P., Sellström, U., Emenius, G., & de Wit C.A. (2012). Indoor Air Is a Significant Source of Tri-decabrominated Diphenyl Ethers to Outdoor Air via Ventilation Systems. Environmental Science & Technology, 46, 5876–5884.
[120] As reviewed by Pakula C. & Stamminger R. (2010). Electricity and water consumption for laundry washing by washing machine worldwide. Energy Efficiency, 3 (4), 365-382.
[121] In general, more than half of textile produced in the world is now syntethic. The assumptions related to the share of synthetic clothes in laundry might be discussed further. Probably, synthetic textiles, inclusive sportswear, are washed more than clothes from natural fibers such as wool pullovers, according to the Norwegian Institute of Consumers Research.
[122] See for example this industry-based review of mand-made fibers as contaminants in indoor air describing it as a recent and growing area of concern: Warheit,D.B., Hart,G.A., Hesterberg T.W , Collins, J.J., Dyer,W.M., Swaen, G.M.H., Castranova,6V., Soiefer, A.I. & G.L. Kennedy (2001). Potential Pulmonary Effects of Man-Made Organic Fiber (MMOF) Dusts.Critical Reviews in Toxicology, 31(6), 697–736.

the effluent from laundry machines or sinks in Norwegian households, although such filters exist on the market in some other countries. Microplastics entering the sewer would be divided between fractions discharged to sea and a fraction retained in sludge at the sewage treatment plant[123].

We would expect a large fraction of indoor dust, in particular the largest particles, to be vacuum cleaned and hence go with the municipal rest waste fraction to incineration. But water-based or dry cleaning of floors and surfaces are strong traditions and also the use of microfiber mopping has gained momentum as a result of indoor air health concerns. Effluent from cleaning with wet or dry mops as well as washing of air conditioner filters would go in the drain and add to laundry emissions.

6.4.2. City dust and road wear

In the first pilot studies of microplastic abundance in the coastal waters near Norway, in Skagerrak, both Norwegian and Swedish researchers have pointed out that a large fraction of particles found in the sea seem to be related to city dust, e.g. asphalt and car tyres[124]. City dust in urban runoff is known as a significant pollution to waterways[125][126]. These particles have so far not been counted as microplastics. But they probably should be, because a substantial portion of the constituants of city dust is plastics from polymer based material e.g. tires and building materials. Researchers studying storm water runoffs from cities to Norwegian fjords, find they are substantial sources of a wide range of building surface and traffic related pollutants[127].

Origin: City dust
Number of sources: every town or city has numerous sources.
Plastic types: Synthetic rubber, paint polymers.
Haz.additives: yes
Particle size, mm: city dust most easily transported in sewer often have median size around 0.1. Tyre dust 0.06-0.08 or smaller.

Figure 6-8 Plastic paints are weathered and comes off the wall in small fragments

Sector description

About 20% of all plastic demand in Europe is for construction and building materials. Many

[123] As suggested for example by: Wilford, B.H., Shoeib, M., Harner, T., Zhu, J., & Jones, K.C. (2005). Polybrominated Diphenyl Ethers in Indoor Dust in Ottawa, Canada: Implications for Sources and Exposure.Environmental Science & Technology, 39, 7027-7035. There are now also some evidence of presumably paint related fragments (polyester thermoset plastic) in sewage, from Sweden: Magnusson, K., & Noren, F.(2014). Screening of microplastic particles in and down-stream a wastewater treatment plant. Report.IVL Swedish Environmental Research Institute.
[124] Norén, F., & Naustvoll, L.-J. (2010). Survey of microscopic anthropogenic particles in Skagerrak. Klima- og forurensningsdirektoratet Norge Rep. TA, 2779(2011), 1–20.; Norén, F., Norén, K. & Magnusson, K. (2014). Marint mikroskopiskt skräp. Undersökning längs svenska västkusten 2013 & 2014. (Report, in Swedish). IVL. Rapport 2014:52. Länsstyrelsen i Västra Götalands län, Vattenvårdsenheten. Sweden.
[125] Zgeib S., Moilleron, R., Saad, M., Ghassan, C. (2011). Partition of pollution between dissolved and particulate phases: What about emerging substances in urban stormwater catchments? Water research, 45, 913 -925.
126 Cornelissen, G., Pettersen, A., Nesse, E., Eek, E., Helland, A., & Breedveld, G.D. (2008). The contribution of urban runoff to organic contaminant levels in harbor sediments near two Norwegian cities. Marine Pollution Bulletin, 56, 565–573.
[127] For example: Jartun, M., Ottesen, R.T., Steinnes, E., & Volden, T. (2008). Runoff of particle bound pollutants from urban impervious surfaces studied by analysis of sediments from stormwater traps. Science of the Total Environment, 396, 147–163 and Cornelissen et. al. (2009) already cited.

modern building materials contain plastics, see table 6-2 below for some examples[128]. Annual use in Europe for decorative paint on outdoor surfaces was as mentioned in earlier chapter about 3.5 kg per capita. The modern paint systems are to a great extent plastic polymer based using a variety of polymeric resins such as styrene butadiene copolymers, polyvinyl acetate, acrylics, alkyds, and polystyrene in concentrations often about 25% of paint volume[129].The common "latex" coatings for example consist of particles of high molecular weight polymers. Scouring and weathering on these modern house surfaces will emit microscopic plastic particles[130].

Table 6-2 Plastics commonly used in building construction materials in Norway

PVC	Roof covering foil, window panes, gutters, wall tiles
SBR (Synt.rubber)	Roofing felt, playground tiles
Polyurethane (PUR)	Foam sealant, insulation
Polystyrene (EPS)	Insulation blocks, cement composites, sandwich panels

Plastics are used also in road materials. In order to improve the properties (viscosity) of asphalt, polymers are added to some bitumen. The materials used are SBR (Styrene Butadiene) and SEBS (Styrene Ethylene Butylene Styrene Copolymer/ "SEBS Rubber"). In brief, the polymers make the asphalt stiffer on warm summer days and more flexible on cold winter days. The use is limited in Norway to some prioritized roads as these polymers are very expensive, and we have no data on volumes used.

Another abrasion surface made of plastics on the roads is the road marking paint/ yellow paint[131]. On Norwegian roads these are partly thermoplastic, partly polymer paints.

Figure 6-9 Road marking paint

From experts working for the Norwegian Public Roads Administration we have received the following estimates on the annual amounts of road marking paint used annually (2014 expected use) in Norway for all purposes, also outside public roads:

Table 6-3 Expected use of road marking material in Norway 2014

Thermoplastic marking (white and yellow)	12.476 tonnes
Paint marking	1.066 tonnes

[128] For an extensive review about plastic materials in Norwegian buildings see for example: Sten Hansen, A., Reitan, N.K., & Andersson, E. (2012). Plast i byggevarer og brannsikkerhet. (Report, In Norwegian). SINTEF report.
[129] varies between paint formulations, no exact data made available from Norwegian paint manufacturers.
[130]For example: Jones, M.S. Effects of UV Radiation on Building Materials. Building Research Association of New Zealand (BRANZ), Judgeford. ; Al-Kattan, A., Wichser, A., Vonbank, R., Brunner, S., Ulrich, A., Zuin, S., Arroyo, Y., Golanski, L., & Nowack, B. (In press 2014). Characterization of materials released into water from paint containing nano-SiO2. Chemosphere.
[131] Mentioned as a particle source by for example: Adachi, K., & Yoshiaki Tainosho.(2004). Characterization of heavy metal particles embedded in tire dust. Environment International, 30, 1009- 1017.

For road marking, fillers are a larger than usual amount of the paint volume, and typical thermoplastic elastomer content is hence as low as 1-5%. We have summarized the calculated volumes of polymers to be used in the abovementioned road marking volumes or Norway 2014, Table 6-4.

Table 6-4 Estimated polymer use in road marking Norway 2014

Plastic product/ material	Tonnes
SIS (Styren-Isopren-Styren)	85
EVA (Etylen-vinylacetat)	66
PA (Polyamide)	57
AM (Acryl-monomer)	112

The wear surface of car tires, the tread, is partly based on synthetic polymers, namely Styrene Butadene Rubber (SBR) approximately 60%[132], in a mix with natural rubber and many other additives constituting the rest of the weight.

Road dust entering the sea through air or storm water will hence have a component of microplastic from road materials, marking and car tyres.

Emission factors decorative coatings, tyre dust and road paint

The OECD has made emission factors[133] for decorative paints derived from experts within the paints industry. They estimate about that about 3% of the initial solid fraction is spilled or weathered off during its use lifetime (before the remaining paint is removed and deposited). (For emissions of used paints from renovation work, see chapter 6.3.2.)

For road dust, the use of spikes and salting at Norwegian roads wintertime is a regarded as a major reason for dust generation. The technical lifetime of road markings is not many years in this environment, but studies of road marking degeneration mainly focusses on reflective and safety performance, not on particle abrasion. Nevertheless, we found studies both in Norway[134] and similar climate zones[135][136] where large parts of the road marking is completely absent after one seasons abrasion and weathering.

Particle generation from car tyres have been studied more in depth[137]. An emission factor from UK studies is 0.1 g per vehicle-kilometre (vkm) for a passenger car[138]. For commercial vehicles like buses and trucks the abrasive loss of tyre material is more extensive, a Russian

[132] Erik Skabo, Polytrade, Norway, personal communication.
[133] OECD (2009). OECD SERIES ON EMISSION SCENARIO DOCUMENTS. Number 22. EMISSION SCENARIO DOCUMENTS ON COATING INDUSTRY (Paints, Laquers and Varnishes).
[134] Johansen, T.C. (2013). Road trials for Road Markings with enhanced Skid Resistance. Report 253 (In Norwegian with English summary). Norwegian Public Roads Administration.
[135] Hirawa, M., Kasai, S., Takemoto, A., & Aita, H. (2010). Development of Recessed Pavement Markings that Incorporate Rumble Strips. Journal of the Eastern Asia Society for Transportation Studies, Vol.8.
[136] Reviewed e.g. by Bahar, et. al. (2006). Pavement Marking Materials and Markers: Real-World Relationship Between Retroreflectivity and Safety Over Time. Report, web only. National Cooperative Highway Research Program, USA.
[137] Reviewed recently by for example by Pant, P., & Harrison, R.M. (2013). Estimation of the contribution of road traffic emissions to particulate matter concentrations from field measurements: A review. Atmospheric Environment, 77, 78-97.
[138] Luhana, L., Sokhi, R., Warner, L., Mao, H., Boulter, P., McCrae, I. Wright, J. & Osborn, D. (2004). Measurement of non-exhaust particulate matter. Report 96 pp. Project sponsored by the EUROPEAN COMMISSION Directorate General Transport and Environment.

study[139] gives the following values based on weighing of the used tyres compared to their new weight:

Table 6-5 Russian estimates on tyre wear/particle generation per km, based on tyre weight loss.

Tyre designation	Intensity of wear (g/km)
Passenger car	0.033
Light commercial	0.051
Commercial	0.178

In Norway, private cars are annually running a total of about 30 billion vehicle km, while heavy transport vehicles 5 billion vehicle km[140].

Earlier estimates

Sweden: tyre rubber dust emitted annually, 10.000 tonnes, or slightly above 1 kg per capita[141].

Germany: 110.00 tonnes of particles were lost from tires, about 1,4 kg/ capita/ year[142].

<u>Emission estimate exterior paints: 130 tonnes.</u>

To calculate the amounts of microplastic particles weathered from decorative coatings (exterior wall paints) on outdoor surface a rough first estimate using the OECD emission factor of 3% and a Norwegian annual consumption of such paints of 17500 tonnes (3,5kg per capita X 5 million) and assuming 25% polymer content the amount of polymer microparticles annually could be 130 tonnes. This is annual weathering only, not adjusted for standing mass variations, and not including removal by maintenance covered by earlier chapter 6.3.2.

<u>Emission estimate road paint: 320 tonnes.</u>

The volume of polymers used in Norwegian road marking per year according to sector sources are 320 tonnes. We assume that the annual consumption about reflects the annual abrasion, even if we know that some markings are overpainted or removed.

<u>Emission estimate tyre dust: 4.500 tonnes</u>

Passenger cars (UK factor): 30 billion vehicle km X 0.1g = 3.000 tonnes

Passenger cars (Russian factor): 30 billion X 0.033 X 4 = 3.960 tonnes

Heavy transport (Russian factor) 5 billion X 0.178 X 4[143] = 3.560 tonnes

Using the Russian emission factor, and assuming a polymer (SBR) content of roughly 60% this gives emissions: 7.500X0.6= 4.500 tonnes polymer in particles from tyres.

These estimates are well in line with the Swedish and German estimates.

As the emission of microplastic particles from tyre wear turns up as a potential major source of microplastic contamination to the sea we have collected additional Norwegian data from experts within the tyre recycling system to verify and strengthen the estimate of tyre

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[139] As cited by: Anonymous (2012). Particulate Matter Emissions by Tyres. Informal Document GRPE-65-20 (65th GRPE, 15-18 January 2013, agenda item 16). Transmitted by the expert from the Russian Federation.

[140] Our own estimate, based on data from Brunvoll, F., Monsrud, J., Steinnes, M., & Wethal A.W. (2005). Transport and environment. Selected indicators for the transport and communication sector. Report. Statistisk sentralbyrå, Statistics Norway.

[141] According to Noren (2010), already cited.

[142] According to Nova Institute (2014), already cited.

[143] Assuming for simplicity 4 wheels only for the heavy abrasion. Many trucks have more wheels.

material loss per year on Norwegian roads, not only based on the international emission factors.

In Norway, 52.000 tonnes of tyres were collected by Norsk Dekkretur in 2013[144], of which heavy trucks amounted to about 10.000 tonnes (These tyres have been re-treaded in average 2,5 times. No other tyres are re-treaded in Norway). Each tyre has an average life of 2-4 years and the weight when collected is about 10-15% less than the new tyres, or re-treaded tyres. If we assume that the arising (put on the market) of passenger and light commercial cars amount to 42.000 tonnes (e.g. 12,5% less weight), the weight of the new tyres amount to. 48.000 tonnes, the losses during the lifetime equal 6.000 tonnes. When it comes to the heavy trucks, the weight of the collected tyres equal 10.000 tonnes. As these tyres have been re-treaded 2,5 times, we might say that the volume collected equal 25.000 tonnes new/ re-treaded tyres. This equals an arising of (e.g. 12,5% less weight) of 28. 571 tonnes arising, and thus 3.571 tonnes of losses.

In total the losses of all tyres thus amount to 9.571 tonnes annually, based on a stable market and stable use. The losses equal the dust emitted from tyres. Assumed a 60% share of synthetic material, the emissions of synthetic organic particles thus equals ≈ 5.700 tonnes.

Control measures and trends

According to the Norwegian Public Roads Administration (Statens Vegvesen), dusts from roads mostly end up in nature. Tunnels and the E6 highway close to Gardermoen Airport (due to a fresh water reservoir) are exemptions, whereby the water from the roads is treated. In the inland countryside, road dust would to a large extent be absorbed and trapped in soil along the roads, while in urban environments with impervious surfaces most particles both from building weathering and roads will get washed into sewer and transported towards the sea. A 50:50 division between emissions to soil and to water is earlier calculated for Norwegian road dust in general[145].

Further studies are needed to calculate these emissions more in detail from the material flow perspective. For estimating emissions to the sea it seems interesting to map the transported particle fraction in surface waters and storm sewers from roads and urban surfaces. Also to look closer at transport via air would be relevant.

6.4.3. Indoor dust at public and commercial buildings

Several international studies have looked at the different constituents of indoor dust in public buildings, like town halls, schools or commercial buildings, like shopping malls. Synthetic paint and textile fragments have been identified as common particles[146] and would vary a lot with source materials and abrasion processes present from place to place. For example, textile shops might be point sources for microplastic dust within shopping areas[147].

[144] Hroar Braathen, personal communication.
[145] Amundsen, C.E., & Roseth, R. (2004). Utslippsfaktorer for forurensninger fra veg til vann og jord i Norge. Pollutant emission factors from roads to water and soil in Norway. Report (in Norwegian). Statens Vegvesen.
[146] Gyntelberg, F., Suadicani, P., Nielsen, J.W., Skov, P., Valbjørn, O., Nielsen, P.A., Schneider, T., Jørgensen, O., Wolkoff, P., Wilkins, C.K., Gravesen, S., & Norn, S.(1994). Dust and the Sick Building syndrome. Indoor Air, 4, 223-238.
[147] Suggested by Maskey et. al. (2011) already cited.

Plastics are probably slightly more common in such high abrasive environments, compared to homes. For example flooring in commercial and public buildings are often heavy duty thermoset plastic materials, polyurethane or PVC, that are easy to wash and maintain[148].

Laser printer toner is of some relevance to offices as it consists to a large extent of microscopic thermoplastic powder, these polymer particles diameter are about 2- 10 micrometres. The powder is melted onto the paper when printing. Usually this is a styrene-acrylate copolymer[149]. Spill of toner products will hence add microplastic particles to the indoor environment.

The floor area of public buildings in Norway is about 50 million m^2, while private commercial buildings 80 million m^2.

Emission estimate public and commercial indoor air: 200 tonnes

By using again an emission factor of about 1-2 grams microplastic dust per m^2 building floor area (Indoor dust, chapter 6.4.2) this would give a total annual microplastic dust generation of about 200 tonnes.

A lot of these microplastic particles would be handled by commercial cleaning companies; emptied down the drain or of another unknown destiny. A fraction of the finer particles would also go outdoors air via indoor air ventilation.

6.4.4. Wear and tear of products in aquaculture, fishery and agriculture

Wear and tear of mulch and ensilage film etc. in agriculture, and wear of synthetic ropes and nets in aquaculture and fisheries are obvious sources of microplastics and mentioned quite frequently in the microplastic literature. Common plastic materials for marine ropes are nylon, polyester, polyethylene and polypropylene, but there exist a wide range of brands and special formulations including other polymer types.

There are a few reasons why we think these are a small and rather neglectable microplastic source for Norway. Importantly, this is largely a question of definitions. For example, when the quality of such products deteriorate, in Norway they would be defined as waste and discarded (in proper or improper ways) rather than being considered as still in use. Hence they would fall in the category secondary sources, see chapter 7.

Material testing of synthetic ropes and fibers have shown that UV-weathering and abrasion of poorly maintained gear may be substantial[150]. There are however, material and routine improvements to amend product weathering and abrasion in most sectors. For safety reasons ropes used at, for example fishfarming plants and for shipping are replaced regularly. Equipment will typically be replaced before getting brittle enough to shed substantial amounts of fibers (as opposed to lost or discarded plastic materials[151] mentioned in a later chapter).

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[148] Norsk forening for betongrehabilitering (2012). Løsninger basert på herdeplast. Report (In Norwegian).
[149] Ewers, U., & Nowak, D. (2006). Gesundheitsschäden und Erkrankungen durch Emissionen aus Laserdruckern und Kopiergeräten? Gefahrstoffe – Reinhalt. Luft 66, 5, 203-210.
[150] Early review by: Klust, G. (1982). Netting materials for fishing gear. 2nd ed. FAO Fishing Manuals. and Klust, G. (1991). Fiber Ropes for Fishing Gear. FAO fishing manuals.
[151] Se for example this recent study nicely matching microfiber fragments found in the sea with weathering of different fishery related items: Jang, Y.C., Lee, J., Hong, S., Lee, J.S., Shim,W.J., & Song, Y.K. (2014). Sources of Plastic Marine Debris on Beaches of Korea: More from the Ocean than the Land. Ocean Science Journal, 49(2),151-162.

There are certain abrasion points that are difficult to avoid during most uses of lines and nets. Ropes get defragmented to a "fuzzy" surface at abrasion contact point, and ropes and gear are dragged along the seabed and ship deck regularly. Weight loss at abrasion points before replacement is strictly necessary and may be as much as several tens of percent. But there is no data on how much microplastic generation this would constitute, as material studies have looked at the strength loss of, for example, plastic films and ropes rather than micro particle creation. A guess would be that on a recreational vessel maximum loss of fragments from ropes in use for moorings and docking per year would be in the range of grams, while on a large vessel, a fishing boat or an aquaculture farm in the range of kilograms. At a national level this would add up to hardly more than a few tonnes and insignificant compared to other microplastic sources.

More important and much larger emissions of plastic fibers would be shed from plastic equipment discarded, abandoned or stored outdoors for a long time[152]. Unfortunately this is known in both the farming and fishing/aquaculture industry, where private landfills/long-time stores still are quite common and spread all around Norway. A particular case is when whole farms, fish farms or fishing vessels are abandoned and left to deteriorate.

In Norway, polyamide based nets for fish farming are washed for fouling and retreated with antifouling paint on a regular basis. This industry is based on the seaside, has water emissions, and is probably a point source for microplastics. To what extent is not known.

6.5. Microplastic particles created by waste handling and recycling

It is obvious that improper waste handling, for example, dumping plastic items in nature, may contribute to marine littering and hence secondary formation of microplastics through natural degradation. But what if existing and fully legal 'best practice' waste handling systems themselves are actively creating microplastics? We see several waste streams where macroplastics are defragmented to microplastics.

6.5.1. Landfills

Landfills were the key final disposal solution for waste up to the 1990s in Norway. In Europe, about 40- 50% of all plastic waste is still landfilled; even in the UK landfilling is the normal waste disposal solution. At active landfills, air drift is a key challenge. Air drift is defined as plastics taken by the wind to the nearby environment. Even though the landfills have tried to reduce the problem and have made some clean ups, plastic waste around landfills and also former landfills can be regarded as a source for microplastics. Microplastic pollution has not been a topic widely considered within the municipal waste industry so far. However, experts on landfilling and hazardous substances in Norway believe that landfills might have been, and still are, leaking microplastics. Ongoing projects on landfill mining, for example at GLT in Gjøvik, might give further answers to this as the plastic waste found in former landfills, now is examined for possible recycling[153].

Recent scientific studies worldwide suggest that several plastic types can be degraded and abraded more rapidly and to a larger extent in landfills than earlier believed[154]. The

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[152] For example: Rees, A.B., Turner, A., and Comber, S. (2014). Metal contamination of sediment by paint peeling from abandoned boats, with particular reference to lead. Science of the Total Environment, 494-495, 313-319.
[153] Berg, Bjørn, GLT, Norway, personal communication.
[154] Reviewed for example by Wester Plesser, T.S. (2013). Bisfenol A i sigevann fra deponier. Mulige kilder. Report in Norwegian with English summary. SINTEF Byggforsk.

temperature[155], pH and the physical compacting process contributes to this. It is suggested that plastic particle emissions in the leachate and air from landfills and similar waste stores might explain part of the leachate contents of certain chemical micro pollutants together with general weathering and UV degradation, the so called "abrasion hypothesis". These studies suggest that, for example, dust from breakdown of padded furniture plastic foams like polyurethane in landfills might cause an increasing pollution problem[156]. Also it is important to remember, that microplastics from earlier primary sources mentioned in this report, such as shredder fluff, vacuum cleaner bags, sewage sludge and sandblasting grit often end on the landfill. There is an ongoing discussion in Norway on the needs for more elaborate leachate treatment.

In order to close in on some estimates of microplastics in Norwegian landfill leachate it seems possible to recalculate, for example, certain flame retardant or heavy metal findings to the corresponding plastic amounts necessary to create these levels. In a recent report from Avfall Norge (Waste Norway) such micro pollutant emissions are summarized and also compared to other Norwegian emission points. Total leachate volume from 88 Norwegian landfills in 2007 was reported as 9.100.000 m^3/year. Among the contaminants measured was PBD99, 80 grams per year emitted. If the amount measured was to be recalculated as emission of, for example, PBD-contaminated plastic dust concentrations like found in WEEE shredder dust (concentration in fine grained plastics there of 7,5 mg PBD99 per kg) this would hypothetically equal a landfill emission of (80.000/7,5) 10 tonnes of plastic particles annually. This is assuming all the leachate was particulate. Similarly 441 kg of Bisphenol A was found in the total leachate. This is typically present in polycarbonate plastics and epoxy plastics and according to industry sources bound in the material so no emissions should be expected. Even with no evidence of breakdown of these plastics in Norwegian landfills, it indicates that they are not completely inert and might give away free monomers or particles. We leave for other studies further elaboration on what contaminants could be suitable for such extrapolations and to produce emission estimates.

6.5.2. Organic waste treatment

Organic waste (e.g. compost, biogas digest) and sewage sludge collected for reuse as soil improvement or landfill material is often contaminated with a certain percentage of macroplastic items, like fragmented waste bags, hygienic articles, Q-tips and similar items that are not filtered out.

In some treatment processes the waste is further shredded, which might create even smaller plastic particles[157]. Content of plastic items smaller than 4 mm in such waste is not regulated,[158] [159]and might in practise be an unintended incentive for microplastic production in this waste flow. In addition, sewage sludge is heavily contaminated with synthetic plastic

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155 Saido, K., & Taguchi, H. (2004). Low-Temperature Decomposition of Epoxy Resin. Macromolecular Research, 12 (5), 490-492.
156 Stubbings, W.A., & Harrad, S. (2014). Extent and mechanisms of brominated flame retardant emissions from waste soft furnishings and fabrics: A critical review. Environment International, 71, 164–175.
157 Avfall Sverige (2014). Microplastics in the biogas process. Prestudy. Report.
158 Shah, A. A., Hasan, F., Hameed, A., & Ahmed, S. (2008). Biological degradation of plastics: A comprehensive review. Biotechnology Advances, 26(3), 246-265.
159 Norwegian regulation, Gjødselvareforskriften.

fibers from textiles[160], and by chemical tracers which might indicate presence of also other polymer particles[161].

Sewage treatment and sludge

In Norway about 225.000 tonnes of sewage sludge is used annually for soil application, about 60% to farmlands, the rest to parks and landfill covering. There exist several estimates on the relative and absolute amounts of microplastic particles retained in sewage sludge:

Table 6-6 Examples on the relative and absolute amounts of microplastic retained in sewage sludge.

Particles retained in sludge (measured or *assumed)	Study site
About 90%* of incoming	Sweden 2014[162]
About 95%* of incoming	Russia 2014[163]
47-80%* of incoming	Netherlands 2014[164,165]
400 large microfibers per kg	USA 1998 and 2005[166,167]
20 per litre old sludge sediment	UK 2011[168]

Some of these studies have noted that the plastics are still present in the soils tens of years after application, both at the original site and following particle transport pathways on the land field where applied. Also noted visually, but not well documented by numbers, was that some treatment processes of the sewage sludge/and other composts mentioned below might defragment long microplastic fibers to shorter ones. Hence sewage sludge reuse might be a source of defragmenting some of the original effluent microplastic into smaller pieces, hence increasing emission particle numbers, but not volumes. We find mentions internationally (UK and USA for example) on the use of macerators/grinders/comminutors at wastewater channels and at some treatment plants in the sewage system[169]. Macroplastics entering the sewage system are covered in chapter 7.5.3. If shredded during sewage treatment this could add primary microplastics, but we have received no information from the sector on to what extent such grinders are common in Norway. However, this will be covered by the parallell Environmental Agency study on microplastics via sewage.

A reasonable estimate, having in earlier chapters already estimated incoming microplastics for sewage treatment plants to more than 1.000 tonnes per year from households and city

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[160] Zubris, A.K., & Richards, B.K. (2005). Synthetic fibers as an indicator of land application of sludge. Environmental Pollution, 138, 201-211.

[161] For example highly elevated levels of plastic related flame retardants compared to background levels in soil: Suominen, K. Verta, M., & Marttinen S.(2014).Hazardous organic compounds in biogas plant end products—Soil burden and risk to food safety. Science of the Total Environment, 491–492, 192–199.

[162] Magnusson, K., & Noren, F.(2014) and Magnusson, K., and Wahlberg, C. (2014), as already cited.

[163] Talvitie, J., Heinonen, M. (2014). Preliminary study on synthetic microfibers and particles at a municipal waste water treatment plant. Report. Baltic Marine Environment Protection Commission HELCOM. 14.pp.

[164] Brandsma, S.B., Nijssen, P., Van Velzen, M.J.M., & Leslie, H.A. (2014). Microplastics in river suspended particulate matter and sewage treatment plants. IVM Report R14/02. 20 pp.

[165] Gueldre, Greet de, Aquafine, Belgium, Personal communication.

[166] Habib, D., Locke, D.C., & Cannone, L.J. (1998). Synthetic fibers as indicators of municipal sewage sludge, sludge products, and sewage treatment plant effluents. Water, Air, & Soil Pollution, 103, 1-8.

[167] Zubris, A.K., & Richards, B.K. (2005). Synthetic fibers as an indicator of land application of sludge. Environmental Pollution, 138, 201-211.

[168] Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011). Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. Environmental Science & Technology, 45(21), 9175-9179.

[169] For example: USEPA (2003). Wastewater Technology Fact Sheet. Screening and Grit Removal United States Environmental Protection Agency.

dust indoors and outdoors, would be that many hundred tonnes of microplastics are deposited on Norwegian soil surfaces annually contributing to background emissions from runoff. This is though just redistribution of earlier mentioned primary sources and not to be counted as a unique source.

Biowaste

But some other sources and treatments of bio waste might actually create new microplastics. Compost and digestate produced from source separated food waste from Norwegian households and industries is used widely in farmland and distributed to consumers as soil improvement products. About 280.000 tonnes of source-separated food waste from households and industries is collected for biological treatment in biogas and composting plants[170]. Norwegian food waste from households is collected mainly in plastic bags (green bag), "compostable" bio-bags made from corn starch (and polyester) and water proof paper bags. Collected waste is delivered to composting or biogas plants that transform the waste into fertilizers and soil conditioners.

The food waste fraction, in addition to food particles, also contains other wastes, including plastics that users have discarded, partly by mistake into the green bag. (Increased use of plastic packaging on food, like on each cucumber, might increase the amount of plastics thrown in the green bag.) The food waste from households may therefore contain an unexpectedly high volume of plastic and other waste due to mistakes by consumers.

Annual waste analyses undertaken by the Municipal waste company for the Drammen Region (RfD) completed in the period 2005 to 2013, shows sorting errors ranging from 3.6 to 11% by weight, with an arithmetic average of 7.1%[171]. If this result is representative for all Norwegian food waste supplied composting and biogas plants this equals nearly 20.000 tonnes of plastic, paper and metal per year.

Composting and biogas plants are equipped with a pre-treatment to remove non-food material. However, the effectiveness of the equipment varies. In large part, this mechanical equipment consists of grinders and shredders. In practice, sorting errors are removed at different steps in the process. Any plant that will bring their fertilizer products based on organic waste to the market, must demonstrate compliance with the requirements of the fertilizer trade regulation. This applies to a requirement that foreign objects (glass, metal, plastic) > 4 mm in size should not exceed 0.5% by weight of the dry matter product. Some plants, such as Romerike Biogas Plant, that receive source-separated food waste from households in Oslo, have tightened this requirement to apply to foreign particles > 2mm. This is consistent with the Swedish certification scheme for digestate and compost[172].

The Technical Research Institute of Sweden (SP) and the Institute for agricultural and environmental technology (JTI) has conducted a preliminary study to investigate how plastic enters the biogas process and how pre-treatment affects the occurrence of microplastic bio fertilizer [173]. The conclusions of the feasibility study are that it is impossible to determine to what extent micro plastic is generated in the preparation, but by the grinding and crushing of the substrate, there is theoretically a chance that microplastics are generated. It is known

[170] Mepex Consult AS (2011). Økt utnyttelse av ressursene i våtorganisk avfall. Report, in Norwegian, for Miljødirektoratet.
[171] Mepex Consult AS. (2013). Plukkanalyse 2013 – våtorganisk avfall. Report in Norwegian, for Renovasjonsselskapet for Drammensregionen IKS.
[172] SPCR 120 Certifieringsregler för rötrest (SP 2014) og SPCR 152 Certifieringsregler för kompost(SP 2014)
[173] AvfallSverige (2014). Mikroplaster i biogasprocessen – Förstudie (JTI/SP – 2014).

that some plastic passes the pre-treatment facilities and enters the bioreactors. It cannot be expected that substantial degradation of the resin occurs in these reactors, since the residence time is relatively short. Microplastics passing through the bioreactor will normally end up in digestate/compost.

Emission factors

Based on the existence of clear regulatory requirements that must be documented by a separate declaration and that all facilities have the equipment to remove foreign objects, it can be assumed that the contents of the plastic particles in compost and digestate> 4 mm is low. However, so far as we have been able to ascertain, there is no investigation of the content of micro plastics in either compost or digestate from Norwegian plants.

A European review shows that impurities (defined as: above 4 mm size, visible impurities) in compost and biogas digestate from European bio waste is typically in the range from almost zero to about 0.3% dry weight[174]. The dry weight content of incoming bio waste is about 40%. From industry sources it is regarded reasonable to assume that about 50% of the impurities are plastic. This would give a plastic contamination factor of about worst case 0.3% X 0.5 X 0.4 =0.06 % of the bio waste wet weight, of which most is close to microplastic sizes.

We add to this a value for the potential impurity fraction below 4 mm that is not normally counted. Brinton (2005)[175] has shown this can be substantial, and as a default value we would here assume this fraction equals the counted fraction by weight. A total microplastic factor for bio waste can hence be about 0.12 %.

Emission estimate microplastics generated in compost and biogas sludge: 336 tonnes

Based on the above mentioned emission factors derived from European data on content of impurities in biowaste, we can estimate microplastic content of the end products in Norway to be up to 0.12% of 280.000 tonnes = 336 tonnes per year.

Control measures and trends

Increased use of bio waste for compost, biogas and increased use of the end products for soil improvement is a general trend and ambition of this sector in Norway as in the rest of Europe. The need for quality control and efficient sorting mechanisms for getting the plastics out of the end product is linked to this ambition and hence also expected to improve.

6.5.3. Paper recycling

Paper recycling factories receive large amounts of printed paper (some printing techniques apply thermoplastic to the paper surface), glossy paper (which may have a plastic film), grease- or waterproof food packing paper (which may be plastic laminated) and other paper that might also have been polymer modified in some way.

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[174] Saveyn, H., & Eder, P. (2014). End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): Technical proposals. Report. European Commission. Joint Research Centre. Institute for Prospective Technological Studies.
[175] Brinton, W.F. (2005). Characterization of Man-made Foreign Matter And its Presence in Multiple Size Fractions From Mixed Waste Composting. Compost Science & Utilization, 13 (4), 274-280.

Often paper, cardboard and corrugated board are coated by polymers. For example, magazine paper is coated, as is grease proof/ pizza baking paper and several other paper products in order to obtain a smooth surface and to be water resistant. The coating is often latex based. Latex can be synthetic. Latex is defined by IUPAC as a "Colloidal dispersion of polymer particles in a liquid." Other types of paper coatings include polyethylene or polyolefin extrusion coating, silicone, and wax coating to make release liners, paper cups and photographic paper. Products like beverage cartonnes are laminated with PE layers.

Sector description
The main recycler for Norwegian beverage cartonnes is located in Sweden, Fiskeby in Norrköping. There is only one major factory in Norway, Norske Skog plant in Skogn, that recycles de-ink paper. Another factory, Ranheim, recycles corrugated board.

According to Norwegian Environment Agency, microplastics have not been an issue for water discharge permits from paper recycling plants.

Emission factors
According to the PFI, the Paper and Fiber Research Institute, the issue of microplastics has not been discussed within the industry, including the paper recycling industry. Plastic amounts in paper sent for recycling can be up to several percent[176]. Hence emission seems possible and likely.

Several OECD reports on emissions from de-inking facilities and factories for recycled paper production show that discharges of polymer particles are possible. Recent exploratory sampling directly at the intertidal waste water outlet of a Dutch paper recycling factory, located by the Southern North Sea, revealed very high concentrations of micro plastic granules[177].The microplastic concentration just at the effluent pipe was up to 30 mg/l. With a permitted daily water emission volume at this production plant of 3.500 m^3/day or 1×106 m^3/year, a worst case daily emission: 105 kg, and annual emission: 30 tonnes.

Emission example scenario Norway: 60 tonnes

Norwegian paper recycling factory (Skogn) have a total water emission volume of: 7x106m^3/year. Amount of recycled paper in Skogn: 29%, so about that much effluent is related to recycled paper intake. Measured suspended solid (SS:particles) in effluent is 0,6 tonnes per day, indicating that the water treatment plant cannot remove all particles. A worst case microplastic emission based on the Dutch findings could be about 60 tonnes microplastic. (30mg/litre X 0.29 X 7X1106).

6.5.4. Metal shredding

Metal shredding yards within the WEEE (electric and electronic equipment) and ELV (End of life vehicles/ cars) waste streams create large amount of so called called 'shredder fluff'[178] which mostly consists of plastic dust: For example shredded car dashboards, stuffing from car seats and insulation from fridges and freezers. These fractions of the shredder items have no particular metal value or material recycle interest. Shredder fluff has been a 'difficult' waste fraction to find good end-uses for. It is a mix of many different plastic materials, it might be

[176] http://www.ineris.fr/ippc/sites/default/interactive/brefpap/bref_pap/english/bref_gb_traitement_niveau.htm
[177] Dubaish, F., & Liebezeit, G. (2013), as cited earlier.
[178] A recent review of the contents in this waste stream is for example COWI (2013). UTRANGERTE KJØRETØY OG MILJØGIFTER I MATERIALSTRØMMER VED FRAGMENTERINGSVERK. Report (In Norwegian). Autoretur.

contaminated with heavy metals and Persitant Organic Pollutants (POP) like brominated flame retardants, and hence is not a good raw material. But still, it is rarely contaminated heavily enough to be regarded as toxic waste. So what is to be done with it? In the Norwegian context, incineration has been tested and found acceptable, but still the most common use has been in landfills[179].

In Norway there are just below ten big metal and WEEE shredders with permission from the Environment Agency to emit certain substances. Dust emissions to air reported for 5 of these sites in the national emissions database and have varied between 2, 5 and 8 tonnes per year for the last 10 years. The permitted amounts are much larger than this, and there are few measurements to show variations. This dust is primarily particulate from coatings as well as plastic foams and plastic articles within this waste (that is, microplastics).

Shredder fluff that is deposited and unprotected against weathering, wind and water runoff is an obvious microplastic source[180]. Relatively high amounts of plastic related flame retardants have been found in wastewater and sediments just downstream some of the Norwegian shredders[181].

Emission estimate shredders: 10 tonnes

This is based on reported values to air per year, adjusted slightly up for an assumed unreported additional discharge to water.

6.5.5. Food waste shredders

Food waste shredders on ships and institutions are also a possible pollution source[182]. Waste shredders installed into kitchen sinks, for getting rid of food waste through the sewage, are popular in some countries but not allowed in Norway. However, aboard fishing boats and probably other vessels in Nordic waters, these shredders are common[183]. There might hence be a risk that plastic film and food wrapping follows the food waste through this maceration, and then goes directly overboard as macro or microplastics. This could be a topic for studies.

6.5.6. Decommissioning of ships and oil rigs

Large ships from all over the world are to a great extent decommissioned at the beaches of India and Bangladesh, where severe microplastic contamination is documented from the dismantling process[184]. Ships and maritime installations contain many plastic items, like insulation, coating, electrical wiring, furniture and textiles. Ideally, installations should be stripped for all potentially hazardous materials before dismantling. Plastics are not on this red list. Polymer based coatings and several kinds of insulation and wiring are rarely stripped

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[179] Miljøverndepartementet (2010) as cited earlier.
[180] The dispersal potential of small particles in fresh shredder fluff is shown by for example Danon-Shaffer, M.N., Mahecha-Botero, A., Grace, J.R., & Ikonomou, M. (2013). Transfer of PBDEs from e-waste to aqueous media. Science of the Total Environment, 447, 458–471.
[181] For example by: Arp, H.P.H., Møskeland, T., Andersson, P.L., & Nyholm, J.R. (2010). Presence and partitioning properties of the flame retardants pentabromotoluene, pentabromoethylbenzene and hexabromobenzene near suspected source zones in Norway. Journal of Environmental Monitoring, 13, 505–513.
[182] Suggested by: Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B-Biological Sciences, 364(1526), 1985-1998.
[183] Nordisk ministerråd. (2010). Håndtering av avfall ombord på fiskefartøyer og mindre fartøyer. (Report, in Norwegian) TemaNord 2009:581 (pp. 24). København.
[184] Reddy, M.S., Shaik Basha, S. Adimurthy, & 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, 656-660.

off, and creation and distribution of some plastic dust even from Norwegian decommissioning sites is likely. There are traces of plastic additives in soil and runoff found at the sites, which may indicate emissions of plastic dust.

Still, Norway has regulated the offshore decommissioning sites strictly at the national level[185]. With strict emission regulations in place to protect the local fjord environment, we do not expect these sites to be a significant microplastic source at a national level. Plastic dust emissions would be mainly from cutting the metal and from abrasion when moving parts, this abrasion would be on very limited coated surface area compared to for example pressure blasting of whole ship sides in open air at shipyards.

6.5.7. Plastic recycling facilities

Plastic recyclers often have a washing system. In fact, the washing process is also part of a sink/float sorting of plastic waste according to the specific gravity of different plastic types. The waste water obviously contains contamination, possibly also some plastic items or particles from the rough washing and/ or agglomeration processes. Some plastic particles from the washing might thus end in the waste water. The leading Norwegian PE plastic film recycler, Folldal Gjenvinning, has an advanced water treatment plant. After treatment the waste water eventually ends in the Glomma river. No information is available on microplastic content.

At municipal and private plastic waste collectors, air drift can be a challenge, including by grinding operations, for example, grinding mixed waste for fuel. Plastics stored in the sun, might also be a source due to degradation.

In total, plastic recyclers might pollute with plastics from the washing process, losses of regranulate and finally from air drift from collected stored plastics. However, plastic recycling is quite limited in Norway and the other Nordic countries. Our plastic waste is mostly exported for sorting and recycling. For example, according to Green Dot Norway, almost all plastic packaging collected separately from households, about 30.000 tonnes, is shipped from Norway to Sweden and Germany for sorting.

[185] Norwegian Environment Agency (2010). Webpage: www.miljodirektoratet.no/no/Nyheter/Nyheter/Old-klif/2010/Mai_2010/Avvikling_av_utrangerte_offshoreinstallasjoner/

7. Secondary sources of microplastics pollution

Secondary sources are those we understand as recontamination with microplastics by some material which is already in the environment, whether originally micro- or macro sized. Also, we split secondary sources into three main categories by mechanism. These are microplastic emitted by:

A) Natural defragmenting of macroplastics by weathering and microbial activity

B) Defragmenting of macroplastics to micro particles directly by animal activity

C) Re-suspension of old microplastic contamination in soil or sediments.

The formation of microplastics from macroplastics as a secondary source (A) takes place, by definition, when plastic macro litter (larger than 5 mm) abandoned in (or near) the marine environment is naturally fragmented into ever-smaller pieces, for example, by UV-radiation or weathering. The rate of such microplastic emissions to Norwegian waters will depend largely on the amount of plastic available for natural defragmentation, and that again depends largely on the input of macroplastic litter, both from Norwegian sources, from land and sea, and long range transport from other countries and oceans. The type of plastics might also play a role in the defragmentation/ biodegradation process, further described in chapter 7.4.3.

The role of defragmentation by animals (B), for example birds, is again dependent on the number of animals and their activities. This source will not be further discussed separately in this report where focus is on litter sources, but some examples will be given.

Re-suspension (C) is dependent on former amounts of plastic littering and thus the amounts of microplastic litter in the sediments. The potential for future re-suspension is probably growing. Re-suspension will not be estimated as a separate national source in this report where focus is on new emissions, but some implications are briefly discussed in chapter 7.9.

In this chapter we will therefore:

- Summarize what is **qualitatively** known about the major Norwegian sources of plastic littering to the Norwegian Sea, and compare this to a description of the plastic littering situation globally.
- Summarize general **qualitatively** and **quantitative** information about marine littering
- Summarize the **qualitatively** and **quantitative** results from different beach monitoring projects and clean-ups as an indicator of plastic marine littering
- Give **quantitative** estimate on the potential maximum loss of plastic debris for selected important sectors
- Describe the **mechanisms and potential rates** at which commonly found plastic debris can be broken down into microplastics
- Give some site specific example scenarios and **a national emission** scenario for secondary microplastics

7.1. A model for macro plastic litter sources to Norwegian oceans

As an introduction to the following subchapters on what is known, and not, about macroplastic sources to Norwegian seas, table 7-1 below gives a breakdown of potential plastic macro litter sources to Norwegian oceans. The table is based on the conceptual model for microplastic sources described in chapter 5, personal communications and the authors' experience. This is a model without ranking the different sources, but instead with an assessment on the existing knowledge of each of these potential plastic littering sources.

The model separates different origins of macro litter that might to a certain extent, sooner or later, end up as micro plastics. The wastes from land can originate both from Norway as well as from other countries. To simplify the model, the last line in the table below summarizes macroplastics from other countries and other oceans. However, macro plastic debris from foreign ships and fishing boats in Norwegian oceans are included in "from Norwegian sea/ territory". In this way we avoid any discussion about what is a "Norwegian" vessel.

Plastic debris discarded onshore might end up directly into the oceans, "From land" or pass through the sewage system (incl. by storm water) via lakes and rivers, all ending up in the fjords and the oceans. The table below lists some examples to illustrate.

Some of the plastic waste listed in the table can be found on beaches. Analyses of beach clean-ups will follow in chapter 7.3. Potential other data sources are listed in the comments column below. As can be seen, few data exists on macro plastic littering in Norway. The lack of data will be further discussed in chapter 9.

The terminal degradation to microplastics might take place on shore or in the marine environment. It is important to stress that plastic macro litter might also end up in the soil onshore or in the sediments as macroplastics. All macroplastic litter does thus not necessarily end up as microplastics in the ocean. This might be the case, for example, for lost fishing nets sinking to the seabed. These processes related to how macroplastics are defragmented into microplastics will have to be analysed further in later studies.

Table 7-1 What is scientifically known about likely macrolitter sources in Norway?

Main mechanism	Sector	Single macro litter source	Comments/ data available
From land, Norway	Municipal landfills	Air drift of plastics possible, if not well covered	Most municipal landfills are under control in Norway, but former drifted plastics can remain in nature
	Industrial and construction waste	Dumping of construction and process waste, such as insulation, plastic cables from dynamite, fibers for concrete.	Poor national data on this source, only anecdotal information and knowledge that much waste is not properly disposed of.
	Private illegal landfills	Illegal landfills	No national data on this source. NGO reports from several counties about tens of illegal landfills in each town or municipality.
	Littering in public spaces as well as from private properties	Parks, recreational spots, roadsides renovated by municipalities	No national data on this source. Anecdotal reports of "more than before".

Main mechanism	Sector	Single macro litter source	Comments/ data available
		Private properties partly renovated	Local data might be compiled on the litter that is cleaned up.
From Norwegian sea/ territory	Fisheries	Waste thrown over board	Some reports on waste from fishing vessels. Reports from harbours might add data on what is delivered.
		Loss of trawls, nets, ropes, incl, "ghost nets".	Reports on collected ghost nets. In general, poor reporting on lost nets
	Aquaculture	Abandoned equipment and sites, incl. shellfish plants	No national data on this source Unclear what is "stored" for later possible reuse and what is abandoned.
		Storm loss of ropes and floaters, and shell fish nets/bags etc.	No national data on this source
	Shipping and offshore	Waste thrown overboard and plastic items discarded in toilets etc. on cruise liners.	No national data on this source
		Loss of ropes, floaters and other equipment. Weathering and defragmenting of wrecks and abandoned vessels, inclusive abandoned leisure boats	No national data on this source Some indications on lost leisure boats in ongoing project for Norwegian Environment agency.
	Seaside leisure activity and recreational boating, incl. marinas	Plastics thrown away directly to the sea when boating, littering from recreation outside public area. Littering and storm losses from marinas (incl ropes, plastic bottles with a rope and floaters)	No national data on this source
Sewage and storm water from Norway	Public sewage treatment plants	Plastics passing mechanical filters, e.g. Q-tips, wipes, condoms, cigarette buds, snuff poaches bio film carriers used in the water treatment	No national data on this source

Main mechanism	Sector	Single macro litter source	Comments/ data available
		City surface storm water drains	No national data on this source
	Regular riverine input	Macro plastic waste emitted directly to lakes and rivers	No national data on this source
		Plastic macro waste brought adrift from land during extreme flooding and storm episodes	No national data on this source
Biological		Birds and fish transport an digest plastics into Norwegian oceans	Some OSPAR research on fulmars
Remobili-zation in Norwegian harbours		Macro plastic waste from the past	No data on this source
By ocean streams from land and sea/ other countries		Beach clean-ups in Norway show, by label etc, that several items stem from Denmark, Sweden, UK and Germany	International studies on marine littering

Knowledge about the relative contributions and total of these Norwegian sources is limited[186], and was summarized in an Environmental Agency report in 2010 [187]. The total amount of annual littering is not known, and no estimates are given for any sector. However, this Norwegian report will be updated with some further data and published in December 2014.

7.2. Macro plastic littering, a global issue

Littering is a problem in almost all countries and every ocean in the world, lakes and rivers included.

Often, littering is regarded as a local problem. However, when it comes to plastic litter, we are connected; by rivers, waterways and ocean streams. How global this issue is, can be illustrated by the 29.000 plastic/rubber toys (ducks, turtles etc.) lost from a ship outside China in 1992. Fifteen years later, 10.000 of these toys were found outside UK, 27.000 km

[186] Recently reviewed and pointed out by for example: Bareksten, J.O. (2014). Plastforureining i marine miljø. Masters thesis (In Norwegian), literature review on plastic littering of the marine environment.Telemark University college.
[187] Hals, P. I., Standal, E., Riisberg, I., Syvertsen, E. E., Kroglund, M., & Bretten, A. (2011). Kunnskap om marint søppel i Norge 2010 (pp. 34). Oslo: Klima- og forurensingsdirektoratet & Direktoratet for naturforvaltning.

away from the starting point. These plastic ducks had presumably crossed the Arctic on their journey.

The Gulf Stream is a last leg in a huge oceanic "conveyer belt" that theoretically can bring a plastic piece from the Caribbean to Norway in less than a year[188]. Modelling of plastic drift in the World's oceans show clearly that such long transport is not just possible, it is also quite likely in several ocean areas[189]. The Atlantic gyre is among the oceanic areas that function as such a sink for drifting waste from several continents. Litter beaching on the Norwegian coast is though more likely from more local sources, as will be shown here.

7.2.1. Global estimates on macro plastic littering

In the literature, some reports refer to studies on the total amount of macroplastic pollution of the oceans. These are of course just very rough estimates, even if they are highly cited:

- A report from UNEP refers to a US study in 1975 estimating the plastic marine litter to 6.4 million tonnes/year. (This study though focused on waste dumping from ships).
- In 1995, another study also concluded with about 6.5 million ton[190].
- Later studies come to different results, from 0.1% (300.000 tonnes) to 10% (30 million tonnes) of total global plastic production.

Assuming that 10% of the plastics produced (plastics products consumed) in 2013 sooner or later will end up as marine litter, this equals 30 million tonnes or about 4.2 kg/ capita in the world. If we instead of 10% littering, assume 1%, this still equals as much as 3 million tonnes plastic per year.

Accumulated, since the first plastic products entered the market in the 1950s, by the 10% and the 1 % assumption respectively, amounts to about 200 million or 20 million tonnes. Such figures are of course very uncertain. In addition, these figures do not take any degradation, sedimentation or any in biotic breakdown into account.

10% or 1%

The 10% assumption is commonly and most recently used. For example, for lack of better information on the secondary microplastic sources, the German Nova institute, on behalf of UBA, the German Environment Agency, refers to Wright et al. (2013) estimating that as much as 10 % of the global plastic production sooner or later ends in the oceans, where it remains and accumulates.

In Northern Europe, studies show that above 90 % of the plastic waste (collected) is now recovered. As waste management systems work quite well, it is realistic that the littering rate in Europe and Norway is lower than in poor countries. On the other hand, our consumption is much higher and offshore activities are also very high, including leisure boat traffic, international shipping, fisheries and oil and gas activities.

The macroplastic pollution rate is probably far lower in Northern Europe (the OSPAR- area) than in many other regions in the world, and may be in the range of 1 -2% of plastic

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188 Albertsen, Jon, Norwegian Institute of Marine Research, personal communication.

189 Lebreton, L. C. M., Greer, S. D., & Borrero, J. C. (2012). Numerical modelling of floating debris in the world's oceans. Marine Pollution Bulletin, 64(3), 653-661.

190 Schneider, Ralph, PlasticsEurope, personal comments, in literature not quite clear which study is referred to. Obviously, a study from 1975 need to be relaced by more recent research and data.

production/consumption. For Norway, this means about 5- 10 kg of macro plastic litter / capita/ year, e.g. more per capita than the world average.

In many other parts of the world, illegal landfilling and littering is in fact the normal treatment of plastic waste: Each side of the road can often be regarded as landfills. However, plastic waste with a high value, like PET bottles, is collected for recycling, professionally or by the informal sector. However, pieces of plastic film, often PE, have very low value, and are thus often not collected in the same way.

Example: Littering is a huge problem in India. For the first time in India, the new central Government has put waste and littering on the national agenda. It is estimated a total production of 10 million tonnes of plastics every year, while the plastic waste amount to 4,5 million tonnes. Up to 90% of the PET bottles are picked up for recycling, while much of the waste is littered, roughly estimated to 1 million tonnes, (equals the 10% assumption) remain unpicked. The situation is probably the same in many countries in Asia, and also elsewhere in the world.[191]

Even in Europe landfilling is still a common "treatment" of plastic waste. In some of these countries the standard of landfills is poor and illegal landfilling and littering is common.

Plastic waste is thus a huge littering problem on shore. By way of the wind, waterways, rain and floods, some of these plastics are transported to the oceans. In addition, legal and illegal landfills are placed close to rivers or the ocean or sometimes the ocean is the dumpsite. Poor waste treatment systems in the world are often regarded as one of the most important reasons for marine litter. In Norway there are many known loopholes in the waste system, and illegal dumping and road littering exists.

From land based sources or from ships

The first studies on marine littering concluded that 80% of the marine litter was from ships, with the remaining 20% from land. Later studies conclude that 80% comes from land (often by rivers), the rest from the sea, from ships and fisheries. Obviously, such figures differ from region to region[192]. For example, some studies for the North Sea region indicate that marine macro litter is 60% land origin and 40% ship/ offshore origin. These figures would vary between different regions in Norway too, especially between north and south, and this is poorly documented by other than anecdotal observations.

It could be discussed whether a general "marine plastic littering factor" like the 1% or 10% shall be based on the production volumes of plastics. As an alternative, some suggests it might be better to compare with the amount ending up as waste. As many plastic products have a long life, such as pipes and cars, the amount of plastic wasted at the moment is much lower than the production of plastic raw materials. In Europe the production in 2012 amounted to about 57 million tonnes, while the plastic wasted was about 25 million tonnes. A problem in this thinking is that although the total waste amount in these studies is defined as the sum of plastics collected for landfilling, incineration or recycling, littering is not part of the model.

Mepex instead regards littering as losses throughout the whole value chain, as of raw material production till the material is used again as recycled material or burnt. This includes

[191] Vijay Merchant, Polycraft, India, personal communication.
[192] As can be sen in review for example by Mehlhart, G., & Blepp, M. (2012). Study on land - sourced litter (lsl) in the marine environment (pp. 128). Öko-Institut e.V. Darmstadt/Freiburg.

loss of plastic material as of raw material production, shipments, converting, further shipments, plastic application in use and even plastics lost at landfills. (In a similar way primary sources of microplastics often are related to wear and tear during the use phase of different plastic applications).

7.3. Identifying marine litter sources based on beach litter monitoring

As we lack data and indicators on plastic litter, the following chapters will refer to different analyses of plastic litter on beaches. These studies can tell us something about the sources, the composition and the trends of plastic waste in the ocean. To some degree, these studies can indicate volumes of litter as well.

From international studies, incl. from OSPAR, it is estimated that 70% of marine litter sinks, while 15% will float around in the oceans and 15% end up on beaches. Interpretation of beach litter surveys are among the few data that exist on potential sources of marine littering in Norway. Such surveys are done within the scientific OSPAR monitoring, by local coastal administrations and by NGOs. None of the studies yet are designed to give any national or even regional estimates on marine plastic littering. But they give strong indications on some important sources of buoyant plastic macro debris.

When reading the below mentioned beach litter results, and in particular where some amount of litter collected is mentioned, it should be taken into account that it has recently been suggested that the litter load estimated in a single beach cleaning sample is more than an order of magnitude below the real amount of plastic actually present on the beach[193]. This is due to a high turnover of plastics entering the beach that may also leave the same beach due to high tide water or by the wind. Additionally, plastic buried in soil or beach sand and are not accessible on the day of cleaning/sampling. As these rates also might vary between beaches, more information is needed before extrapolating to absolute values of litter input to the system.

7.3.1. OSPAR monitoring of 7 Norwegian beaches, preliminary results

Based on the OSPAR guidelines, beach litter monitoring takes place in Norway (in 5 places) and on Spitsbergen (in 2 places). The monitoring of Norwegian beaches is in progress, and a final report is expected after five years monitoring. Some preliminary results are presented here, by a list of the items found ranked by total count of litter items, accumulated for the period of four years 2011-2014 for all the beaches (Table 7-2). According to these data we can conclude that some Norwegian beaches are among the worst regarding marine litter load in Europe[194].

The most common objects found, per 1000 meter of beach, according to Norwegian OSPAR monitoring, at seven beaches accumulated for 2011-2014 are unidentified pieces of string, rope and packing bands:

[193] Smith, S.D.A., & Markic, A.(2013). Estimates of Marine Debris Accumulation on Beaches Are Strongly Affected by the Temporal Scale of Sampling. PLoS ONE 8(12): e83694. ; Eriksson, C., Burton, H., Fitch, S., Schulz, M., & van den Hoff, J. (2013). Daily accumulation rates of marine debris on sub-Antarctic island beaches. Marine Pollution Bulletin 66, 199–208.
[194] Standal, Erlend, Norwegian Environment Agency, represented in OSPAR WG, Norway, personal communication

Table 7-2 Numbers of different litter items found on the OSPAR-monitoring beaches in Norway

Count (1000m beach)	Material, Product (Item ID)	Mepex comments on possible sources
5.844	Plastic: String [23]	Probably fisheries, but also other marine sources possible
917	Plastic: Rope [4]	Probably fisheries, shipping, aquaculture, leisure boats
856	Plastic: Other [9]	
571	Plastic: Bands [8]	
299	Wood: Other [15]	
189	Plastic: Net [6]	Probably fisheries
101	Plastic: Jerry [5]	
85	Plastic: Packaging [3]	
59	Plastic: Buoys [1]	Probably fisheries, but also other marine sources possible
51	Plastic: Gloves [22]	Probably fisheries, but also other marine sources possible
44	Plastic: Fish boxes [2]	Fisheries and fishery related industry

The results so far from OSPAR monitoring show that on the Norwegian outer coast litter related to fishery and other sea based activities is abundant on beaches. Also, plastic fragments of unknown origin, often sheets, are common. It is not known how much of this is related to Norwegian sources vs long range transport sources. According to OSPAR, beach litter monitoring in the Southern North Sea in 2002-2008 found that plastics accounted for 75.3% of items. In the North Atlantic it is estimated that maritime activities and land based recreational activities represents 40% each of the marine litter sources, while the rest stems from waste via rivers, canals and sewage system. [195]

As these results are made for beaches of 1 km length, an upscaling could in theory be done for the whole Norwegian coast of 100.950 km. For example, if the plastic litter generated during one year in average amounts to 10 kg per km, the total plastic beach litter in Norway could be calculated at ≈ 1.000 tonnes. Again, if beach litter accounts for 15% of macro plastics entering the ocean, the macro litter input to our oceans, very simplified, would have been 6.700 tonnes.

[195] Werner, Stefanie, Umwelt Bundesamt, Germany. Marine litter- scope and nature. Presentation in Reykjavik, September 2014.

However, the OSPAR methodology is based on counting items. The weights of the items are not known. The relevance of these beaches to the whole coast should also be evaluated before upscaling. Further data and knowledge is thus necessary for such calculations. Regardless, the composition and the development of a year by year timeseries can be regarded as useful results of the OSPAR studies. If the monitoring also includes defragmentation at the beaches, further conclusions about microplastics generation can be drawn too.

7.3.2. Regular regional beach clean ups

Skjærgårdstjenesten/ Archipelago guard reports to the Norwegian Environment Agency and operates along the Norwegian coast, from the Swedish Boarder up to Bergen. Skjærgårdstjenesten has several duties; one of them is waste collection and clean- ups at places only accessible by boat. In the Oslo fjord region the Oslofjorden Friluftsråd is the secretariat for Skjærgårdstjenesten. The organization compiles statistics of waste collection and also separate reports on litter collected on the beaches. The beach clean- ups consist mostly of littering from the sea.[196]

At Hvaler islands, Norway's first marine national park, about 70% of the coastline is cleaned. In total in 2013, 2.600 waste sacks, of an average of 9 kg, in total 23,4 tonnes, of which 80% plastics (18,7 tonnes), were collected in the whole area.

In general the litter is grouped, but not further analysed, as follows[197]:

- Waste from ships and offshore
- "Household waste" from ships and offshore
- Fisheries and aquaculture: incl major litter (nets/ bags) from shellfish farming
- Tourism and recreation waste

Oslofjorden Friluftsråd reports that in the Oslo fjord there are considerable amounts of biofilm carrier films from sewage plants and other typical items from such plants. Recently, also an increasing amount of snus/snuff pouches, can be found at the beaches. All these items can also stem from cruise liners and ferries. Plastic shopping bags, normally reused for residual waste or other waste in Norway,as are by the Friluftsråd not regarded as a frequent item found at the Oslo fjord beaches. Also reported are some building materials, including insulation such as EPS (plastics). Oslofjorden Friluftsråd cooperates with diving clubs in order to clean up the seabed. Much waste is found, often of more industrial origin and quite some lost nets and traps from recreational fisheries. Less plastic waste than other materials is found on the seabed.

[196] Hansen, Liv-Marit, Oslofjordens Friluftsråd, Norway, personal communication.
[197] Oslofjorden Friluftsråd, Marint søppel, brochure based on KIMO Denmark report financed by Interreg program Clean Coastline, 2014.

7.3.3. National NGO clean ups in Norway

In 2014, 12.191 persons cleaned up 522 beaches and a coastline of 320 km, with 14.000 waste sacks collected. The most common objects found according to the Norwegian NGO "Keep Norway Beautiful" and their national Clean- up day 2014[198] are as follows in table 7-3:

Table 7-3 Total numbers of litter items counted in the national beach clean-up 2014

Plastic item, HNR	HNR Number 2014 (1.000)	Share plastics by Mepex	Comments by Mepex
Undefined plastics	130	100%	All kinds and sources possible
Styrofoam	27	100%	Often related to fisheries, fish boxes
Ropes <50 cm	23	100%	Often related to fisheries, fish farming, shipping
Bottle caps, plastics and metal	19	Partly	Norwegian, but also foreign bottles
Beverage bottles	14	Partly	Norwegian, but also foreign bottles. Brand name/ label might indicate origin. Lack info about material
Cigarettes, snuffs	11	Partly	Partly, may be from from sewage and boats
Food packaging	10	Partly	From residual waste, from fishing boats, shipping, land based. Brand name/ label might indicate origin
Plastic bags	9	100%	Partly from residual waste, from fishing boats, shipping, land based. Brand name/ label might indicate origin
Rope > 50 cm	9	100%	Often related to fisheries, fish farming, shipping
Building materials	3	Partly	Norwegian and international

The summarized results (in number of objects, not but weight) in the table above shows that plastics contribute the most to beach littering, at least by numbers. According to Keep Norway Beautiful, plastics accounted for 68% of all items, excluding styrofoam.

Keep Norway Beautiful has no data on the weight of the collected waste sacks, but estimates are that each sack has a minimum weight of 10 kg. Based on several assumptions, we provide some estimates below.

Based on an average content of plastic of 5 kg in every sack, the collected plastic beach litter of the 14.000 sacks equals a total weight of 70 tonnes. Assuming that the litter intensity is the same along all the coast (100.915 km), and that the litter collected equals one year

[198] Skogen M.H. & Holen M. (2014). STRANDRYDDEDAGEN 2014 - Analyse av data og erfaringer. (Report, in Norwegian). Hold Norge Rent.

contribution (e.g. one clean up every year), the total collectable plastic beach litter, as a very rough estimate, would amount to 22.000 tonnes of plastics per year along the Norwegian coast.

7.3.4. National NGO clean ups in Sweden

In Sweden similar clean- ups are organized by the Swedish sister organizations of Keep Norway Beautiful. The results from analyses at three west coast locations are included in their study, see summary in the table 7-4 below. The results are split household vs industry and then packaging vs consumer products.[199]

Table 7-4 Analysis of plastic litter origin at three Swedish beaches

Place	Share plastics (number items)	Share from consumers	Share from industry	Share packaging	Share consumer products
Strømstad	88,5%	71%	25%	81%	19%
Gøteborg	88,2%	87%	8%	77%	22%
Helsingborg	84,5%	41,4%	21%	46%	53%

The results differ somewhat from the Norwegian reports above in showing a very high share of waste from consumers, such as packaging and typical consumer products and less waste from shipping and fisheries.

Table 7-5 Top 10-list from the three Swedish locations

Product	Numbers	Mepex comments
Plastic bags	5354	By far the biggest share
Unidentified plastic pieces	2021	Probably with low weight, partly defragment
Styrofoam	1159	Probably from fisheries, but also as insulation, and possibly partly defragmented
Rope	446	From fisheries and shipping and leisure boats
Bottle Lids (both plastic and metal)	261	Low share by weight
Cigarette buds	259	Very low by weight
Glass bottles	168	
Beverage cans	158	Swedish deposit system
Drinking straws	115	
Toys	43	

[199] Håll Sverige Rent (2014). Rapport fra Kusträdderne, om skräpet på den svenske Västkysten.

Product	Numbers	Mepex comments
Garbage items	40	
Fishing line	29	Fisheries, probably much higher share by weight
Food bottle	1	

The Swedish beaches cleaned are situated close to cities and thus frequently used by local people.

Different methods are used in these beach clean-ups and monitoring programs. However, all these reports, when repeated, can clarify the generated amounts, composition and the development of plastic littering. Further studies are needed to estimate the volumes by weight and evaluate the impacts on microplastic pollution.

In order to obtain more data from Sweden, also OSPAR studies from the Swedish West- Coast can be used.

7.3.5. Identifying marine litter sources based on trawling and submarine observations

Both in Norway and in other countries, like Germany[200], fishing for litter has been proposed as an activity to clean up marine littering in the seas. This means that the fishermen in addition to their main activity, either actively start to 'fish for litter' and deliver this litter at the harbours for waste treatment or, as the OSPAR approach, sort out plastic waste from their fishing gears in the harbours, as a side activity. Within OSPAR, UK and the Netherlands have been the most active in this field, for some years, partly in cooperation with KIMO. Since 2005, in Scotland more than 600 tonnes of waste has been sorted out this way. The aim is both to remove the waste and use the results for awareness campaigns among fishermen and the public. OSPAR asked all their members in 2010 to start fishing for litter activities. Norway has so far made pre- study[201].

Such activities can serve as a future indicator for marine plastic littering in the oceans, or at least as a further information source.

In Germany there has been some fishing for litter campaigns, also together with the Duale System Germany (DSD) in order to recycle the plastic waste. However, so far, the results seem to be quite poor from the German campaigns[202].

There are some reports from scientific or offshore industry based visual surveys of the Norwegian seabed using remotely operated submarines[203]. In fishery intensive areas, fishing related litter and lost equipment tend to constitute about 80% of the marine litter observed[204], while plastics the rest. Closer to shore there is a wide range of marine litter, but a vast amount of this originates from the waste system of earlier decades where in Norway it was common both for private persons, industry and municipalities to dump waste directly in

[200] http://www.nabu.de/themen/meere/plastik/fishingforlitter/
[201] Standal, Erlend, Norwegian Environment Agency, personal communication
[202] Heyde, Michael, DSD, Germany, personal communication.
[203] Reviewed by Hals et al (2011).
[204] Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., Amaro, T., Bergmann, M., et al. (2014). Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins. PLoS ONE 9(4), e95839.

the sea, or in seaside dumps. Visual surveys hence need to be repeated to tell anything about trends and recent inputs.

7.4. National waste surveys as an indicator of plastic littering

In this chapter so far, we have roughly described the marine littering qualitatively, and with a few general estimates based on overall plastic production figures. Furthermore, beach littering has been used as an indicator.

In this sub-chapter, we will briefly elaborate the possible marine littering based on national studies on plastic waste in Norway. These analyses are partly based on European surveys, party on national statistics and other national reports. The structure of these studies might be used as a tool for better understanding the problem[205]. No such waste statistics in Norway have so far focused on losses and littering of plastics to the sea.

Table 7-6 contains a list of plastic applications and the generated waste and recycling amounts. To each application we have added some comments on the littering potential, of which a share would be marine littering.

Table 7-6 Plastic waste in Norway and potential for litter

Applications	Total amount of waste 2011 Tonnes	Recycled amount 2011 Tonnes	Potential for littering in Norway Comments by Mepex
Packaging	146 600	53 400	Low: for beverage PET bottles the deposit system reduce the risk of littering Low/ medium: Other packaging with good recycling solutions High: Out of home activities/ On the run/ service packaging, such as plastic cups, trays, straws etc.
Household articles	21 000	1 000	Low: Applications normally kept in house
Building and Construction	34 000	2 500	Low/ medium: Some illegal dumping, some items can be taken by the wind at construction sites (insulation/ EPS, tarpaulins etc.)
Furniture	25 000	0	Low/ medium: Outdoor furniture might be discarded in nature
WEEE	43 000	3 000	Low: Take back system in place
ELV	16.500	400	Low: Take back system, valuable items, with refund

[205] Mepex Consult AS (2013). Økt utnyttelse av ressursene i plastavfall. Report in Norwegian, for Norwegian Environment Agency.

Applications	Total amount of waste 2011 Tonnes	Recycled amount 2011 Tonnes	Potential for littering in Norway Comments by Mepex
Agriculture	20 000	10 200	Low/ medium: some illegal dumps and burning. Some film might degrade in the fields
Fisheries	15 500	3 500	Medium: lost or discarded in the ocean, equipment is «stored»/ used for other purposes instead of normal waste collection, no national take back system, see details in table below in chapter 7.XX
Leisure boats/ Composites	1 500	0	Low/ medium: Illegal dumping of boats, no take-back system and costly dismantling.
Other/ unknown	7 000	7 000	
Total	330 069	81 000	

Plastic littering can be considered as losses during the use phase of products, this includes for example, loss of fishing gears and ropes during fishing. The table above, thus needs to be extended to a mass flow analysis and include littering and losses along the whole value chain.

7.5. Volume estimates on four of the major Norwegian macrolitter sources

To find estimates on the total Norwegian macrolittering, a place to start would be to establish estimates for some of the most common fractions seen among beach litter and in underwater surveys. This is still premature, but here are some best estimates with information currently available.

It is most feasible that sewage related or recreational littering plastic items abundant in inner fjord areas originates mainly from local Norwegian emissions. Similarly, Norwegian fisheries and aquaculture related litter should add to what we find so abundant on the Norwegian outer beaches.

7.5.1. Plastic bags and recreational littering

Plastic carrier bags are on top 10 items found, according to some beach studies, inclusive some of the clean-ups mentioned in this report. However, in the Oslo fjord region, plastic bags are regarded as less important items at their coastlines[206]. The OSPAR figures from Norway, referred to in this report, and other OSPAR reports, do not list shopping bags on top[207].

[206] Hansen, Liv- Marit, Oslofjordens Friluftsråd, Norway, personal communication.
[207] Wegpage: www.ospar.org/html_documents/ospar/html/marine_litter_unep_ospar.pdf

According to EU Commission reports, it is estimated that in 2010 every EU citizen used 198 plastic carrier bags, in total 98.6 billion bags, some 90% of which were estimated lightweight bags. These are less frequently re-used than the thicker bags and more prone to littering. Estimates also suggest that in 2010, over 8 billion bags were littered in the EU. They escape waste management streams and accumulate in our environment, especially in the form of marine litter[208].

This means that about 8 % of all bags were littered in 2010. Based on an average weight of 10 grams, the plastic bag litter amounts to 80.000 tonnes. The thicker bags, normally used in Norway are made from LDPE. These bags are probably less prone to be littered than the thinner HDPE bags used in the South of Europe. All bags in Norway are also normally paid for, NOK 1/ bag is a normal price. Since most shopping bags are reused for garbage and empty beverage containers etc. there are good reasons to doubt that the mentioned loss percentage of 8% is relevant for Norway.

Estimate for plastic bag litter: 60 tonnes

Based on information available it is difficult to estimate the number of shopping bags ending as marine litter. A best guess would be 1% of all bags in Norway, that is ≈ 9 million bags annually. As the bags are visible and easy to pick up, a certain amount of these bags are removed by annual clean- ups. We estimate that 0.5% of all plastic shopping bags in Norway end in the ocean, that is, 4 million bags of 15 grams each, or 60 tonnes.

Actions are also taken to reduce the number of plastic carrier bags in many countries, both within the EU and in the rest of the world. The EU is about to take action on an EU level as well. In Norway, a tax on bags is also on the agenda. The challenge related to plastic carrier bags might thus be reduced in future, but see also chapter 7.8.1.2 on biodegradable plastics.

7.5.2. Plastic litter and lost equipment from fisheries and aquaculture

The fisheries and the aquaculture industries both generate waste from their operations. This waste, partly comparable with municipal solid waste, is to a certain extent dumped in the ocean (see chapter 6.5.5). These wastes contain also plastics.

Figure 7-1 Ropes, often made from PP

In addition, these industries also use equipment made from plastics. In the table 7-7 below we have summarized the waste and recycling amounts of these plastics[209]. In this table we have also commented on a possible littering rate.

[208] European Commission (2013). Media release: Commission proposes to reduce the use of plastic bags, 4th November 2013.
[209] Mepex Consult (2013). Økt utnyttelse av ressursene i plastavfall. Report for Norwegian Environment Agency.

Table 7-7 Plastic waste from fisheries and fish farming, Norway 2011

Applications	Total waste mount 2011 Tonnes	Recycled amount 2011 Tonnes	Potential risk for littering in Norway Comments by Mepex
Fish farming rings (PE)	7 000	500	Medium/low: High value of equipment, but also high cost for collection, equipment thus sometimes stored or reused for other, alternative use, with a medium/ low risk for littering
Feeding pipes (PE)	800	150	Medium/low: High cost for collection, sometimes stored or reused for other, alternative use
Nets, fish farming (PA)	2 500	1 500	Medium/low: Delivered to net- washing, some destroyed nest get lost
Ropes (PP)	3 000	600	Medium: Lost or discarded no regular take back system. Lower value
Nets, trawls for fisheries (diverse)	2000	650	Medium: Lost or discarded in the ocean, no regular take back system. Ghost fishing is an issue
Floatation elements (diverse)	200	-	Medium/ high: Lost or discarded in the ocean, no regular take back system, difficult to recycle
Total	15 500	3 500	

Today, some waste management operators collect and export some of these wastes for recycling abroad. The polyamide (PA) nets are washed before exporting. (The washing of these nylon nets, like for other textile washing, might also result in microplastic losses, briefly described in chapter 6.3.3).

The national waste strategy, launched in August 2013 proposed a national voluntary EPR (Extended producer responsibility) agreement with the fish farming industry as basis for a national take back system with very high recycling ambitions and thus a lower amount of marine litter from this sector. So far, no action has been taken in order to establish such an agreement. However, a quite high recycling rate is obtained on some of the fractions due to active waste management companies. In Iceland, such a national EPR systems has been in operation for several years.

Some studies have estimated that 0.1% of all fishing nets in Norway and Sweden being set is actually lost[210]. The Directorate of fisheries in Norway/ Fiskeridirektoratet in Norway, retrieve and remove such ghost nets from the Norwegian ocean. The equipment found stems mostly from Norwegian fishermen.[211]

Huge amounts are removed every year. In 2014, 900 gears were removed: 5.3 km rope, 22 km of fishing lines, 11.6 km of metal wire, 3 shrimp trawls and considerable amounts of trawls and fishing nets and other plastic and metal based equipment. In total 18.000 gears have been removed, in total 500 km in length, since 1983. The directorate regards most of these gears and equipment as losses, due to weather and other operational challenges, not just as discarded/ littered.

According to the Directorate of fisheries, these activities cover the main fishing grounds for Norwegian fishing. However, the Directorate underlines that they do not have a good overview of such losses, inclusive of losses from recreational fishing. The results above, the Directorate would not regard as an indicator of lost equipment. It is reported that fishing equipment often sink to the seabed and thus end up in the sediment there. It is thus difficult to estimate the impact of these lost gears as a source to microplastic pollution.

Based on a Nordic Council report on waste generation aboard fishing vessels, from 7.5 to 17. 5 kg of total waste is generated on a typical Norwegian fishing vessel per day, depending on crew size. Of these about 50% are plastics.

Estimate on fishery and aquaculture related plastic litter: more than 1000 tonnes

Based on previous studies for a recycling system of fishing and aquaculture ropes and nets about 15.500 tonnes such waste is generated annually in Norway. The waste comprise PP-ropes, HDPE cages, HDPE pipes for feeding and PA nets from the fish farming industry as well as PP-ropes, trawl and other fishing equipment from the fisheries. In 2011 only about 3.500 tonnes of this was collected for recycling. Based on the comments above and the results from the clean ups and the removal of lost equipment, the amount of lost and discarded equipment seems to be quite high. More data is necessary as basis for an estimate but a guess would be more than 1.000 tonnes but less than 10.000 tonnes annually.

7.5.3. Sewage related plastic littering

Plastic pieces people put in their toilet or sink, or throw in the sewer, may end up in the sea. In a quite recent UK study, over half the population admitted to flushing items down the toilet instead of putting them in the bin[212]. Sewage treatment plants have mechanical sieving of such waste. However, the problem is that the loss of plastic items both during storm water events and other incidents at sewage treatment plants might let the untreated sewage, including the plastic waste, enter the sea.

Sewage related debris has been estimated to be a substantial source of items encountered as marine littering, both in rivers, on beaches and on the seabed[213]. Public outcry often follows

[210] Reviewed by Brown, J., & Macfadyen, G. (2007). Ghost fishing in European waters: Impacts and management responses. Marine Policy, 31(4), 488-504.
[211] Langedal, Gjermund, Fiskeridirektoratet, Norway, personal communication.
[212] As referred to by: Venning, M. (2009). Sewage Related Debris – another Inconvenient Truth. Presentation. Head of Environmental Regulation, Wessex Water.
[213] For example: Morritt, D., Stefanoudis, P. V., Pearce, D., Crimmen, O. A., & Clark, P. F. (2014). Plastic in the Thames: A river runs through it. Marine Pollution Bulletin, 78, 196–200.

incidents with plastics loss through sewage in Norway. It is not nice to swim in a sea of used sanitary pads, condoms and worse! Yet the sector has by no means contained the problem.

The total volume of sewage effluent water (treated or not) in Norway per year is 952 million m^3. Of this there are regular emissions of untreated sewage of about 3% of total, that is 29 million m^3. In addition, the registered sewage overflow in Norway 2013 caused by storm water was: 15 million m^3.[214] [215]

Example: 16 m^3 plastic biofilm carriers were lost to a Norwegian river system from a single sewage treatment plant in a single overflow event. The lost plastic items were of the size 7.2mm X 9, 1mm (just outside microplastic range, mesoplastic). This single event emitted 16 million plastic pieces[216]. In addition large numbers of Q-tips and similar followed the same outflow.

Figure 7-2 Typical sewage related plastic litter from an Oslofjord beach

To get an idea about the amount of plastics emitted during discharge of untreated sewage, it is possible to extract some data from studies on plastics in Sewage Treatment Plant reject and sludge (the fraction sieved away from the incoming raw sewage). A recent French study showed that plastics in sewage treatment plant reject constituted above 1% dry weight, but in addition, 70% of the reject was sanitary pads, partly with plastics[217]. In a "combined system" which is common in Norway, where storm water is allowed to enter the sewage, the quantity of screening increases during storm and according to UK and US experiences can be as high as several hundred grams per person per day, or 0.22m^3 per 1000m^3 sewage.

<u>Estimate on sewage related macroplastics: 460 tonnes</u>

If only a few grams of plastics, let us say 5 grams which would be realistic based on international literature, on average are thrown in the toilet or on the street near sewer per day from every Norwegian, and about 5% of all Norwegian sewage is actually going untreated to the sea like numbers show, this equals about 460 tonnes of plastics being thrown in the sea. (5 million X 5% of 5 grams x365 days). In this is <u>not</u> included microplastic primary sources, this is just macroplastic items.

7.6. From macroplastics to microplastics

7.6.1. The major natural mechanisms and sites creating microplastics from macro plastics

Knowing the typical rates at which the macroplastic items in the sea leach microplastics would make it possible to get a better idea about the importance of secondary microplastic sources. Yet the rate at which different plastic litter items in the sea turn into microplastics

[214] Berge, G., and Mellem, K.B. (2013). Kommunale avløp Ressursinnsats, utslipp, rensing og slamdisponering 2012. Gebyrer 2013. Report (in Norwegian).Statistisk sentralbyrå/ Statistics Norway. Rapporter 63/2013.
[215] Norwegian Environment Agency, personal communication and printout from stormwater overflow reports database.
[216] Sørum Kommunalteknikk. (2012). Utslipp av Kaldnesmedie, november 2012. Notat. (Report, in Norwegian).
[217] Hyaric, R.L., Canler, J.-P., Barillon, B., Naquin , P. & Gourdon, R. (2009). Characterization of screenings from three municipal wastewater treatment plants in the Region Rhone-Alpes. Water Science & Technology, 60.2.

seems to be poorly investigated at present. The few relevant field studies, see examples in Table 7-8 below, have been finished before any large defragmentation has taken place. Commercial studies on breakdown of plastic or polymers are mainly focussing on loss of polymer strength, rather than defragmentation and particle creation. Also, the polymer literature makes a point that there are no agreed understanding and models on polymer weathering or abrasion[218]. Additionally, lab studies clearly have limited relevance to the variable and complex natural weathering[219].

There are however, a few important rules of thumb to be learned: 1) To break down plastic items into small pieces, the combination of heavy UV-light and mechanical abrasion you find at high energy beaches and shorelines is a perfect recipe. Breakdown deeper in the sea must be much slower. 2) Different plastics, and different plastic shapes, defragment at different rates. It is expected, for example, that thinner pieces get degraded by UV-light relatively faster, because of a larger surface area to weight ratio. 3) Reduction in particle size is no guarantee of subsequent biodegradability of the meso- or micro plastic fragments. The smaller pieces may instead be redistributed by other pathways than the macroplastic and preserved in soil or water.

Figure 7-3 EPS littering

Turnover time of plastic debris might be fast on a single beach, loss to the sea often balancing the inflow. This also means that beaches might be source areas of microplastics generated from the standing stock of macro plastics.

UV-light and abrasion[220]: Light-induced oxidation of plastics is orders of magnitude higher than other types of degradation. Some plastic foam, like polyurethane padding for furniture, and extruded polystyrene (aka Styrofoam) are known as notoriously “crumbly” as soon as they become exposed to the external environment. More durable plastic items, like polystyrene buoys, get a fractured surface from strong sunlight, and small particles are then easily polished off when moving against rock or sand[221]. On some shores the wave energy is so high that the plastic material is rubbed down to smaller particles even without UV weakening as a primer[222].

Biotic defragmentation can also be considerable. Some microorganisms fouling on plastic surfaces and some naturally occurring chemicals attack the polymer surface[223][224], and act together with the UV-degradation to break down the polymer. But there are also mechanisms in which larger animals might contribute to microplastics generation.

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[218] Budinsky, K.G. (1997). Resistance to particle abrasion of selected plastics. Wear 203-204, 302-309.
[219] Concluded in review by: Lucas, N., Bienaime, C., Queneudec, M., Silvestre, F., Nava-Saucedo, J-E. (2008). Review Polymer biodegradation: Mechanisms and estimation techniques. Chemosphere, 73, 429–442.
[220] As reviewed by: Andrady, A.L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62, 1596-1605.
[221] See for example field observations by: Cooper, D. A., & Corcoran, P. L. (2010). Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island of Kauai, Hawaii. Marine Pollution Bulletin, 60(5), 650-654.
[222] Eriksson, C., & Burton, H. (2003). Origins and biological accumulation of small plastic particles in fur seals from Macquarie Island. Ambio, 32(6), 380-384.
[223] Zheng, Y., Ynaful, E. K., & Bassi, A. S. (2005). A review of plastic waste biodegradation. Critical reviews in Biotechnology, 25, 243-250.
[224] Shah, A. A., Hasan, F., Hameed, A., & Ahmed, S. (2008). Biological degradation of plastics: A comprehensive review. Biotechnology Advances, 26(3), 246-265.

Mechanical abrasion and some chemical breakdown of plastics would happen in the chewing mechanism and stomach of abundant macro fauna: seabirds[225], some fish and crustaceans. Field observations and experiments on boring isopods in the Pacific show that a single individual might create millions of microplastic particles when it makes a 6 cm deep burrow into floaters made of EPS[226]. And a special case is when seabirds bring rope pieces ashore, using them as nesting material, making the plastics susceptible to rapid UV degradation and fragmentation. In large bird colonies these biotic aggregations of plastics have created "waste dumps" of tens of tonnes plastic material[227].

Table 7-8 Examples on results from studies on plastic litter break down

Plastic item type	Defragmentation rate	Reference, and comments on study conditions
Polyurethane foam piece (mattress e.g.)	Brittle and gave away fragments already after 4 weeks exposed.	Full sunlight conditions in summer. [228]
Extruded polystyrene blocks or buoys (EPS)	Depending on the shape of the element: more than 10% per year.	Within a year the outer surface 5 cm might be completely defragmented.[229]
Plastic films (bags) Polyethylene Polypropylene	Brittle within a year, annual mass loss estimated from 1%, up to around 5% when exposed to sun and air. Fouling interrupts the UV degradation largely after short time in sea. Estimated 300 years for total degradation in soil.	Consistent results from several studies. Exposed to air,sun or shallow water[230]
Polyurethane flexible foam	40 years: total loss of coherence resulting in powdering.	Suitcase padding, archived in a museum…[231]
Polypropylene ropes and polyamide (nylon) fish farming nets	Strength loss of 50% in 180 days found in India, more in Oman. Linear relationship: breakdown by time.	Exposed to Oman or Indian sunlight[232][233] In Northern Europe sun radiation is lower.

[225]Hilton, G.M., Furness, R.W., & Houston, D.C., (2000). A comparative study of digestion in North Atlantic seabirds. Journal of Avian Biology, 31, 36–46.
[226] Davidson, T.M. (2012). Boring crustaceans damage polystyrene floats under docks polluting marine waters with microplastic. Marine Pollution Bulletin, 64, 1821-1828.
[227] Votier, S. C., Archibald, K., Morgan, G., & Morgan, L. (2011). The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. Marine Pollution Bulletin, 62(1), 168-172.
[228] Hale, R.C., La Guardia, M., Harvey, E., & Mainor, M. (2002). Potential role of fire retardant-treated polyurethane foam as a source of brominated diphenyl ethers to the US environment. Chemosphere, 46, 729–735.
[229] Davidson T.M. (2012) as above.
[230] For example: Andrady, A.L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62, 1596-1605.; O'Brine, T., & Thompson, R. C. (2010). Degradation of plastic carrier bags in the marine environment. Marine Pollution Bulletin, 60(12), 2279-2283.; Muthukumar, T., Aravinthan, A., Lakshmi, K., Venkatesan, R., Vedaprakash, L., & Doble, M. (2011). Fouling and stability of polymers and composites in marine environment. International Biodeterioration & Biodegradation, 65(2), 276-284.; Ohtake Y., Kobayashi T., Asabe H. & Murakami N. (1998). Studies on biodegradation of LDPE - observation of LDPE films scattered in agricultural fields or in garden soil. Polymer Degradation and Stability, 60, 19-84.
[231] Lattuati-Derieuxa, A., Egassea, C., Thao-Heua, S., Balcarb, N., Barabantb G., & Lavédrinea, B. (2013). What do plastics emit? HS-SPME-GC/MS analyses of new standard plastics and plastic objects in museum collections. Journal of Cultural Heritage, 14, 238-247.
[232] Al-Oufi, H., McLean, E.,Kumar, E.S., Claereboudt, M., & Al-Habsi, M. (2004). The effects of solar radiation upon breaking strength and elongation of fishing nets. Fisheries Research, 66, 115–119.
[233] Thomas S.N., & Hridayanathan, C. (2006). The effect of natural sunlight on the strength of polyamide 6 multifilament and monofilament fishing net materials. Fisheries Research, 81, 326–330.

Plastic item type	Defragmentation rate	Reference, and comments on study conditions
Epoxy & acryl	Some breakdown takes place, evident from findings of breakdown products like styrene oligomers.	Laboratory conditions, match with environmental samples [234]
In general	Less than 1-3%/year in sediment/water	Summarized based on studies and experience so far[235]

7.7. Towards the first estimates of total Norwegian volume of marine littering and microplastics from macroplastics

In this chapter we have described macro plastic marine littering and also tried to show how the amounts can be calculated as a basis for further analyses on the role of this litter, as a secondary source to micro plastic pollution. We have identified some important single sources of macrolitter, which together amounts to probably some thousand tonnes of Norwegian plastic litter per year. Other sources are not mentioned with any amounts. We have also mentioned international volume estimates of macrolitter.

7.7.1. A best guess Norwegian emission scenario for secondary microplastics

So far it is speculative, but as a rough estimate and a guess we conclude that a likely Norwegian contribution to macroplastic littering, from both onshore and offshore activities is about 2-4 % of national plastic annual consumptions of about 500.000 tonnes. That is, 10.000 to 20.000 tonnes, annually.

We assume 20.000 tonnes (4% of total plastic annual consumption of plastic products) of plastic littering in Norway, of which 60% originates from land, the rest, 40% from sea. Further assuming that 50% of the land based litter end in the soil on land, while the rest end very soon in the ocean as macroplastics. 6.000 tonnes end in the ocean, together with the 8000 tonnes from ocean based sources, that is a total of 12.000tonnes to the sea. All this will partly sink, partly float around, while the rest will end on beaches and there, to a certain extent degrade to microplastics. At which rate, we still do not know. As degradation on beaches most likely are much faster that in the water, beach litter is more important as a microplastic source than the often used "15% of all marine litter end on beaches" estimate.

Lack of data makes it impossible at this stage to make any estimate on the contribution of Norwegian secondary sources to Norwegian microplastic littering, but it cannot be larger than the aggregated annual input of macroplastics, the standing mass. The annual generation of microplastics from this standing mass of waste could be something in the range of 1%-5% (degradation rate) of the aggregated annual input from the last decades (e.g. 20 X 12.000tonnes x 15% X 1% or 5% = 360 to 1800 tonnes per year, very simplified). However, such rough estimates are of course difficult to prove and speculative, but they give a feeling about the possible range.

[234] Sajiki, J., & Yonekubo, J. (2003). Leaching of bisphenol A (BPA) to seawater from polycarbonate plastic and its degradation by reactive oxygen species. Chemosphere, 51(1), 55-62.
[235] Andrady, T. in Kershaw,P.J. &Leslie,H.(eds.) (2012.) GESAMP Working group 40 Sources, fate & effects of micro plastics in the marine environment a global assessment. Report of the Inception Meeting,13-15th March 2012, UNESCO, IOC, Paris, 45pp.

7.7.2. Estimates on macrolitter amount entering Norway from long range transport

The Norwegian contribution of macro plastic marine littering to our oceans originates from 5 million inhabitants with a strong fishing, shipping and offshore industry. The Norwegian oceans also receive long range transported plastic litter from other territories, both from land and sea, but how much is not known.

Figure 7-4 Plastic litter fragmenting

We believe that the long range transport component is rather high compared to Norwegian sources, because: The population around the North Sea, connected to waterways and rivers ending in the North Sea amounts to about 200 million people, including rivers like Rhine and Thames, which are far more densely populated areas than Norway. Modelling of marine litter drift show that a large share (98%) of landbased litter in the North Sea is actually most likely to originate from the North Sea area, rather than anywhere else[236]. Further north, in the Norwegian Sea, about 97% of the landbased litter is most likely of European origin. See table 7-9 below. The important and largest source sectors mentioned in reviews on marine littering and recent North Sea studies are: fisheries, aquaculture and shipping, storm and flooding events, public littering to urban environments and from recreational activities in the coastal zone, construction waste, waste dumping and sewage related items[237].

Table 7-9 Regional contributions to marine litter of the North Sea and Norwegian Sea accumulation zones, results from Lebreton et. al. 2012 modelling with two terrestrial release scenarios.

SOURCES Region of litter origin	Accumulation zone (% litter from each source region)			
	North Sea a	North Sea b	Norwegian Sea a	Norwegian Sea b
South America East	0.03	0.12	0.09	0.24
Central America East	0.09	0.42	0.26	0.75
North America East	0.50	0.81	1.03	1.70
Canada West	0.10	0.00	0.26	0.00
Africa West	0.04	0.10	0.07	0.15
Africa North	0.01	0.07	0.03	0.13
Russia East	0.08	0.00	0.22	0.00
Northern Europe	98.71	98.38	97.17	96.75
Canada East	0.30	0.00	0.57	0.00
Russia West	0.15	0.10	0.31	0.28

[236] Results from Lebreton et. al. (2012), modelling plastic litter drift worldwide. A global ocean circulation model was coupled to a Lagrangian particle tracking model to simulate 30 years of input, transport and accumulation of floating debris in the world ocean. Relative input of drifting particles to the model was based on urban area per watershed, or as an alternative model on coastal population.

[237] See recently reviewed for example by Interwies, E., Görlitz, S., Stöfen, A., Cools, J., Breusegem, W., Werner, S., & de Vrees, L. (2013). Issue Paper to the "International Conference on Prevention and Management of Marine Litter in European Seas".

Regions not mentioned did not show any drift into these two seas according to the modelling. a) watershed based release scenario b) population based release scenario

The Norwegian coastal current moves rapidly northwards along the whole stretch of Norwegian Coast and is fed pollution from the Gulf stream, the Baltic Sea and the European rivers and coastal areas, in addition to local Norwegian sources. About 1.000.000m^3 water/s moves this way bringing along whatever litter is there, it takes just weeks or months for a piece of floating litter to reach Norway from middle Europe, or reach the Arctic from southern Norway. Onshore winds are an obvious process by which much will be beached. It is also important to emphasise that Norway would also be an exporter of macroplastic waste with the ocean currents to oceans outside our own territories. Our plastic waste can thus end up on foreign beaches. Imported plastic litter might also leave our territory again, visiting many different beaches on the journey.

7.7.3. Beach scenarios on microplastic generation from macroplastics

To our knowledge, no good models exist on fragmentation rates of marine plastic debris, and even models and knowledge about the accumulation rates of macro litter in Norway are absent. The following scenarios, table 7-10 and 7-11 are simplified guesses about how a standing mass of plastic litter on a beach would defragment to microplastics. Among the assumptions are simplified hypothetical defragmentation rates based on chapter 7.6.1., combined with knowledge about the typical amounts litter found on Norwegian beaches at a given time.

Table 7-10 Microplastic generation scenario at an inner fjord low energy beach.

Major plastic types	Mix of sewage related items and recreational littering.
Amount of plastic litter	250 kg
Fragmentation rate	1%
Annual amount of microplastic generated	2.5 kg

Assumptions: Litter reflects mainly local sources, like what found in the near city beach cleaning surveys. UV breakdown is high. Abrasion is low.

Table 7-11 Microplastic generation scenario at an outer fjord/costal current high energy beach.

Major plastic types	Pieces of ropes, plastic sheets and styrofoam
Amount of plastic litter	300 kg
Fragmentation rate	5%
Annual amount of microplastic generated	15kg

Assumptions: litter reflects a mix of local and faraway sources, like what found in the official OSPAR counts. Both UV breakdown and abrasion is high.

7.7.4. Conclusion on microplastics from macroplastic littering

We have here in chapter 7 discussed the generated amounts of plastic marine macrolitter entering the Norwegian oceans. Due to lack of data, we do not wish to conclude on the amounts. However, a very best guess for Norwegian sources would be in the range of 2% of plastic consumption, e.g. 10.000 tonnes. In addition, we have to take into account the net “import” of macro plastic litter by the sea currents from other countries, especially UK, Germany, Denmark and Sweden.

For estimates on an annual generation of microplastics, any gross figures of macrolittering per annum must be added to the already aggregated macro litter in the ocean. In this calculation, sedimentation and total biodegradation also have to be taken into account. Removed macro plastics from the seabed (retrieved and removed fishing gears) and plastics removed from the beaches by clean- ups have to be taken into account too, before calculating the generation of microplastics from the macroplastics. More studies are needed before we have the necessary elements in place for building a model able to estimate microplastic emissions from Norwegian secondary sources.

It is still possible to conclude from a pure mass flow perspective that the annual Norwegian contribution of macroplastics to the sea (and hence also fragmented microplastics from this) can hardly be very much larger than the direct primary emissions of microplastics for which several substantial sources are identified and estimated in chapter 6.

7.8. Biodegradable and Oxo-degradable plastics vs. microplastics

Plastic items degrade, some more slowly than others, depending on the kind of plastics, the additives used and of course the conditions where the degrading takes place. In order to improve quality of the plastic products, avoid degradation and thus prolong the life, special additives are used (Appendix C), for example in products that are exposed to the sun.

During the recent years, other materials and additives are used too, for the opposite reason, e.g. in order to start defragmenting the plastics as basis for further degradation. We might call it a sort of medication of plastics. In this chapter the key issue is to answer to which extent biodegradable and Oxo-degradable plastics can generate microplastics. Secondly, whether biobased or fossil based plastics make a difference.

There are some confusion about definitions on bioplastics vs. biodegradable plastics etc., it is important to underline the differences[238]:

- Bioplastics encompasses a whole family of materials, which differ from conventional plastics insofar as they are biobased, biodegradable or both.
- The term biodegradable refers to a chemical process during which microorganisms that are available in the environment convert materials into natural substances such as water, carbon dioxide and biomass, here artificial additives are not needed

The following table on biobased and biodegradable plastics illustrate the differences further, also with some examples on common plastic types.[239]

[238] http://en.european-bioplastics.org/bioplastics/
[239] http://en.european-bioplastics.org/bioplastics/

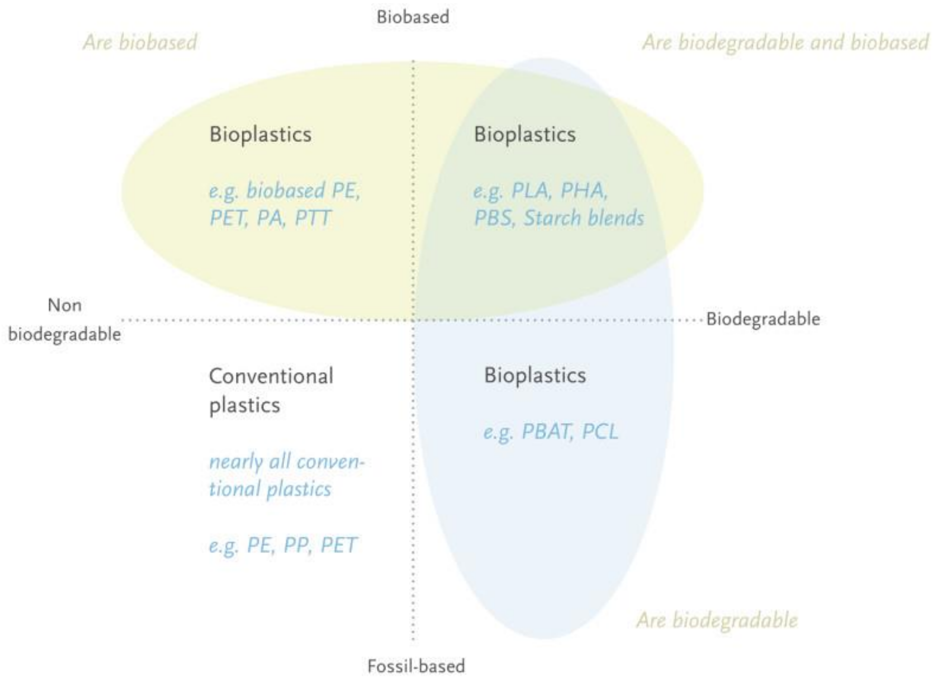

Figure 7-5 Biobased vs. fossil-based plastics, biodegradable vs. non-biodegradable plastics

Oxo-degradable plastics

Oxo-degradation is identified as resulting from oxidative cleavage of macromolecules[240], and additives are used to facilitate this[241]. Oxo-degradable plastics can be either fossil- or bio-based. The bio plastics industry does not regard Oxo-degradable plastics as biodegradable. The stakeholders are constantly arguing on these issues and more knowledge is needed to understand the processes of degradation and biodegradation. Oxo-degradable plastics have been much debated in Europe and it seems that these kinds of plastics now are increasing elsewhere, as in Middle East, rather than in Europe. However, some carrier bags in Norway, are marked as oxo-degradable[242].

Biodegradable plastics

Other plastics are also developed in order to be compostable or biodegradable. These biodegradable plastics can be either fossil- or bio-based. In the literature, often plastics are divided in fossil based and bio based. Some products are also made by a mix of fossil- and bio-based plastics, for example the Coca Cola PET bottles recently introduced in Norway. For both groups of plastics and thus independent of the raw material used, there are different products that are more or less degradable and even compostable. There are many alternative products on the market and many claims regarding the properties of the different products.

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[240] according to CEN/ TR 15351

[241] The standard defines the processes, not materials, which means that the definition of Oxo-degradable plastics is not provided, according to Deconinck, S., & De Wilde, B. (2013). Benefits and challenges of bio- and Oxo-degradable plastics. A comparative literature study, OWS N.V, Belgium.

[242] For example carrier bags from the TGR stores in Norway are marked with: "This bag is oxo biodegradable and will naturally break down after 18 months".

The use of these plastics have so far been limited and thus do not play an important role for microplastic generation up to now. However, further growth is expected, not the least for applications that are typical of litter, such as packaging. In addition, these plastics are discussed as part of the marine microplastic problem. Thus, there are good reasons to study their development and do research on all kinds of degradable plastics and their impact.

7.8.1.1. Production volumes and applications

Compared to the annual global plastic production of about 300 million tonnes, biodegradable and compostable plastics amount to a very small, but rising share, including all kinds of biobased plastics as well, probably in the range of just 1-2 million tonnes in 2012.

The chart below, Figure 7-2, differentiates between biodegradable plastics (fossil or bio based) and non-biodegradable bio based. As can be seen from the chart, the market is slowly growing, mostly for bio-based plastics, such as green PE, e.g. plastics with the same properties as other (fossil) plastics.

The chart does not include Oxo-degradable plastics, normally fossil plastics with additives to initiate degradation. We have not found any data on Oxo degradable plastics.

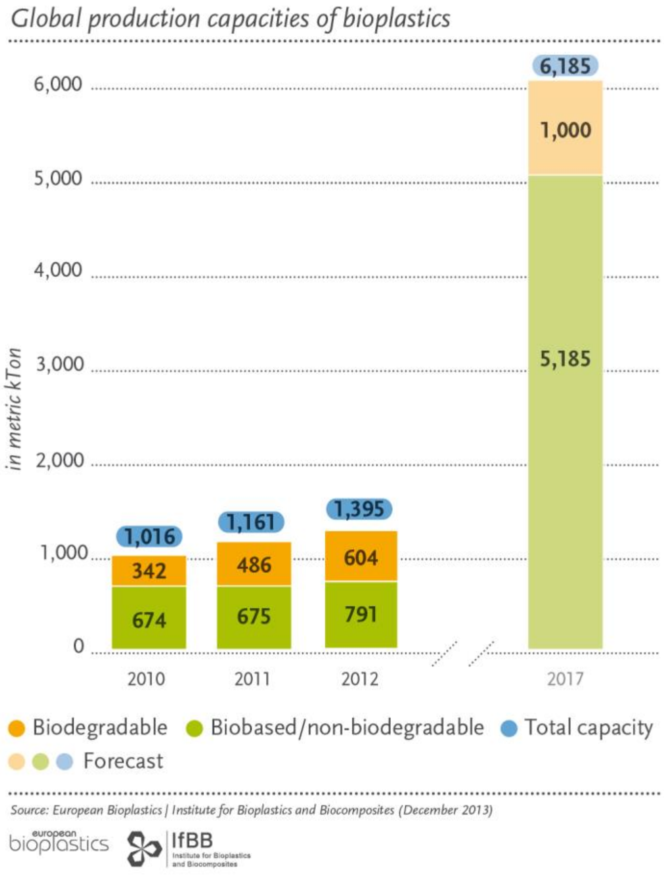

Figure 7-6 Global production capacities of bioplastics (Source: European Bioplastics)

Typical application for biodegradable, compostable and Oxo- degradable plastics are plastic shopping bags, waste bags, inclusive bags for kitchen waste for compost, service packaging for catering and beverage bottles. The bio-bags sold in Norway for kitchen waste are examples on starch blended based bags. In addition, some service packaging, catering is listed as an important product group.

On the chart below, Figure 7-3, the global production capacities are related to different applications in 2012.

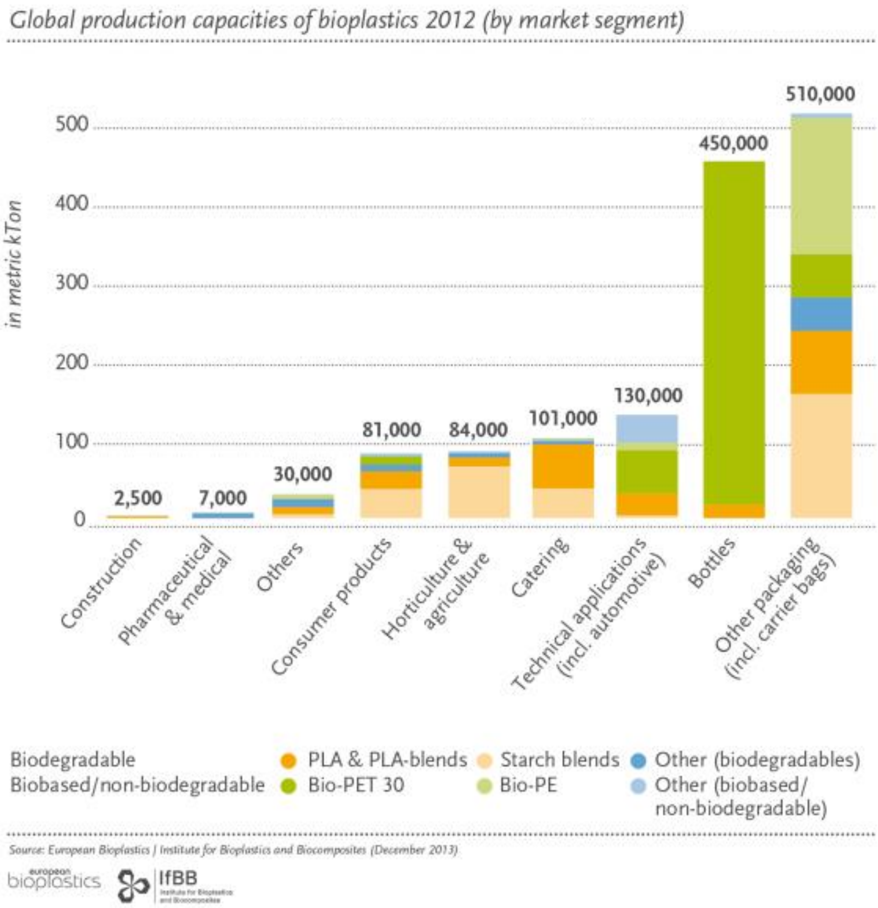

Figure 7-7 Global production capacities of bioplastics 2012, by market segments. (Source: European Bioplastics)

Biobased/non-biodegradable: As can be seen from the chart bio- PET, often called plant-based bottles, is one of the largest applications. Bio-PET has the same properties as fossil-based PET, both regarding recycling as degradation. The same can be said about the bio- PE, often called green PE. Green PE is used to a certain extent in the Nordic market, for example as toilet paper packaging.

Bio based plastics, such as green PE from sugar cane and in the future bio based plastics from the woods[243] will be more common, this is also indicated in the graph above.

[243] Wik, Pär, Trioplast, Sweden, personal communication, presentation at Polymerdagene in Norway, September 2015

Biodegradable: PLA and PLA blends are used in bottles and other packaging, catering products and several other products, often products exposed to littering. Starch blends are also used in several products, like the well-known bio-bags in Norway. These bio-bags are designed for composting and can be certified according to the European standard for industrial compostable products, EN13432. Horticulture and agriculture is one sector where these products are promoted, for example for mulch film. Probably we will see some further growth in compostable and biodegradable plastics and in addition, a variety of different types of such materials. However, due to unpredictable degradation, farmers in Spain often do not use these products any more.[244]

In several applications, beverage bottles and carrier bags, the biodegradable products are used side by side with other plastic products. As the different kinds of products are challenging to sort from each other and because some of the biodegradable products can harm plastic recycling, the use and disposal of biodegradable plastics are debated within the plastics industry. One PLA bottle can contribute to severe quality problems in a PET recycling plant. In a similar way, the new biogas plants, replacing former compost plants, especially in northern parts of Europe, do not want any plastics (including "compostable) in their processes.

7.8.1.2. Biodegradable or Oxo-degradable in marine environment

So far, there is no international standard available, which appropriately describes the biodegradation of plastics in the marine environment. However, some standardisation projects are in progress at both ISO and ASTM level. In addition, the European project OPEN BIO addresses the marine biodegradation of bio-based products. European Bio Plastics, representing the industry, thus call for a standard on how to measure marine biodegradation for plastics in the marine environment[245].

According to the position paper of European Bio Plastics: "EuBP does not claim that bio plastics degrade faster in the marine environment, as they do not find any current standard describing this degradation as sufficient. However, some papers have found that certain bio plastic materials "disappear" faster in such environments - however it is still an area where a lot of research should and will be done in the upcoming years".

Plastics are designed to meet some defined properties, for example to be compostable. Standards, like EN 1324, are used as a tool in the market.

Some research on biodegradation of "biodegradable plastics" in the marine environment has still been undertaken during the last years. An example is that California Department of Resources Recycling and Recovery tested PLA and PHA (Poly-hydroxy-alkanoate) in 2012[246]. The aim was both to understand biodegradation and any chemical intermediates that might be released during degradation. Both PLA and LDPE plastic bags were used for comparison to the PHA. The two Mirel PHA samples passed the biodegradation requirements[247] by converting more than 30% of the carbon in the sample to CO_2 in six months. The PLA and the plastic bag did not biodegrade and did not pass the requirement. Neither of these plastics are

[244] Caldeiro, Alberto, Cicloplast and Cicloagro, Spain, personal communication.
[245] Issbrucker, European Bioplastics, Germany, personal communication and web site on marine litter.
[246] Greene, J. (2012) PLA and PHA Biodegradation in the Marine Environment. Report by Department of Resources Recycling and Recovery, State of California.
[247] Of of ASTM D 7081

claimed to be biodegradable in the marine environment. The report also concludes that neither PHA nor PLA released fragments contained any hazardous byproducts.

This report also mentions studies showing "some disintegration" of a thick PHA bottle during 12 months, but not from a thick PLA bottle. The report does not mention the word microplastics. The question about microplastic generation during the process seems thus unclear.
So far, literature on defragmentation and degradation in the marine environment, as far as we understand, has not focused on the issue of microplastics from degradable and biodegradable plastics. Further studies are needed in order to better understand the impacts on marine littering and as source for microplastics of these degradable plastics. In further studies, it is important to focus on the key applications, and on how they break down and specifically if microplastics are generated as a result.

7.9. Sediments and soils as a macro plastic sink and/or microplastics source?

The pathways and fate of microplastics in the sea is topic of a different study commissioned by the Environment Agency. We still wish to mention the sedimentation of both macro and microplastics here briefly, because it is highly relevant for two aspects of microplastics emissions: 1. Trapping of macroplastics (and large microplastics) before they can get further fragmented 2. Resuspension.

Plastic items are commonly found at the sea surface or washed up on the shoreline, but general assumptions for plastic litter in the sea is that a large share quite rapidly sinks to the seabed[248]. For plastic litter, like for all other particles and items in the ocean, how far they are transported in the sea is always a question about staying afloat or sinking and settling in the sediments. Many plastics are buoyant and remain so until they become waterlogged or amass too much epibiota (marine fouling) to float[249]. Studies have found certain areas of the seabed where macroplastic litter tend to aggregate densely, for example, within the depositional fields of large rivers, slightly seaward of the splash zone on beaches, and seaward of big cities[250]. This might be the final destination and resting place for large amounts of macro plastics, because it is largely separated from the intense UV radiation and high energy turbidity in the surface waters of the coast. In sedimentary ocean locations the plastics would slowly get buried together with other settling items on the ocean floor.

The anoxic preservative conditions in sediment is well known, considering archaeological findings of even very old wood items when properly buried. That the even less biodegradable plastic would then potentially be preserved unchanged for many thousand years in the seabed is therefore not a controversial hypothesis. Similarly, plastic deposited in soils[251], e.g.

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[248] Some sink-out mechanisms recently reviewed and proposed by Cozar et. al. (2014). Plastic debris in the open ocean. Proceedings of the National Academy of Sciences, 111 (28), 10239–10244.
[249] A nice study showing how biofouling might change the buoyancy of small or large plastic items are: Morét-Ferguson, S., Law, K. L., Proskurowski, G., Murphy, E. K., Peacock, E. E., & Reddy, C. M. (2010). The size, mass, and composition of plastic debris in the western North Atlantic Ocean. Marine Pollution Bulletin, 60(10), 1873-1878.
[250] Galgani, F., Leaute, J. P., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., Goraguer, H., Latrouuite, D., Andral, B., Cadiou, Y., Mahe, J.C., Poulard, J.C. Nerisson, P. (2000). Litter on the Sea Floor Along European Coasts. Marine Pollution Bulletin, 40(6), 516-527.
[251] Hardly anything is known by now about contamination levels of plastic and microplastic in soils, according to Rillig, M.C. (2012). Microplastic in Terrestrial Ecosystems and the Soil? Environmental Science & Technology, 46, 6453−6454.

buried from sand movement into beach dunes[252], would also be preserved to some extent. And degradation slowed down compared to in the open air and sunlight.

BUT, in timescales of decades and more, even some defragmenting of this macro plastic litter might be expected. Marine organisms might contribute to this. This urges a caution when opening old sediments or soils by excavation or dredging, as it might create pulse-emissions of microplastics. Both from secondary generation, and from originally primary sources.

[252] Recently shown high abundance of microplastics deep in beach sediments: Turra, A., Manzano, A.B., Dias, R.J., Mahiques, M.M., Barbosa, L., Balthazar-Silva, D., & Moreira, F.T. (2014). Three-dimensional distribution of plastic pellets in sandy beaches: shifting paradigms. Scientific Reports, 4, 4435.

8. Summary of major microplastic pollution sources

Based on the analyses in chapter 6 and 7, a table listing the sources and the calculated emissions of each source is provided below (Table 8-1).We underline that the calculations must be regarded as a first estimate or best approximation. Further information is needed to make sound calculations. In chapter 9 we describe some of the most important knowledge gaps and uncertainties.

According to our understanding of microplastics (see Appendix B, Definitions) annual microplastic emissions from Norwegian primary sources, where figures exist, amounts to above 8000 tonnes annually. Tyre dust, is by far the most important single source, followed by abrasion and particle shedding from polymer based paint and textiles. All emission estimates made in this report about the primary sources are listed and also summed in the table.

The figures for macrolitter and hence the secondary sources are not complete. Some secondary sources are indicated by the annual generation of lost or discarded macroplastic items, and a best guess of annual Norwegian macrolittering of the sea would be about 10.000 tonnes, but there is not enough knowledge about rates and amount of these plastics ending up as microplastics. Further studies are thus necessary before the primary and secondary sources can be compared.

We conclude that primary sources play an important role to microplastic marine pollution. More work has to be done in order to calculate the importance of the secondary sources in order to compare with the primary sources. Until more data is available we conclude that both sources are important, and from a mass flow perspective, may be of equal importance to the microplastic pollution of Norwegian oceans.

This study has focussed on assessing and weighing potential upstream sources, not the downstream fate of the pollution which will be covered by other studies. Still several pathways and their approximate relative fraction is mentioned in this report. We have summarized this knowledge in table 8-2. It shows emission estimates directly to sea from each source when adjusting the upstream figure for assumed source specific retainment of microplastics to for example sludge and soil. The table shows that the relative importance of the different sources does not change much whether you take the upstream or downstream perspective. Total emission volumes downstream would be half or less of the 8000 tonnes estimated upstream.

Table 8-1 Summary of emission estimates for Norwegian sources to microplastic pollution

Mechanism	Source group		Tonnes	% of total	Possible pathway	Dominant plastic type
Designed	Consumer products, all		**40**	0.5	*drain, sludge*	PE, PMMA, PTFE
	Commercial products, all		**100**	1.2	*drain,soil,air,sea*	
Production Spill	Transport spill		**250**	3.0	*sea, soil*	PS,PE,PET,PVC
	Production discharge		**200**	2.4	*drain, sea, air*	
	Accidents		**n.a.**		*sea, runoff, air*	
Abrasion by commercial maintenance	Ship paint		**330**	3.9	*sea, seaside*	epoxy,PU,A,S
	Marinas		**400**	4.8	*sea, seaside*	Epoxy
	Building repair		**270**	3.2	*sewer, soil*	
	Laundries		**100**	1.2	*Drain*	
Wear and Tear during use	Household	Laundry	**600**	7.1	*Drain*	PS, PA, A, PU
		Dust	**450**	5.4	*drain, air, waste*	
	City dust outdoor	Road paint	**320**	3.8	*sewer, soil,air*	SIS, EVA, PA,
		House paint	**130**	1.5	*sewer, soil, air*	PVA,A,PS,SBC
		Tyre dust	**4500**	53.6	*sewer,soil, air*	SBR
	Indoor city	Dust	**130**	2.4	*drain, air*	
Waste shredding	Plastics recycling		**n.a.**		*drain,sludge, air*	PS, PA
	Illegal dumping, paint		**100**	1.2	*soil, sea*	
	Landfills		**n.a.**		*air, water*	
	Biowaste		**336**	2.4	*soil, water*	
	Paper recycle		**60**	1.2	*water*	Latex, PE, S
	WEE and ELW		**10**	0.1	*air, water*	ABS and more
	TOTAL PRIMARY SOURCES		**8.396**		***UPSTREAM***	
Macrolitter		*Tonnes as Macrolitter*				
	Fishery	**Above 1000**	n.a		*dumped,lost*	PA, EPS, PP
	Sewage	**460**	n.a		*drain*	various
	Plastic bags	**60**	n.a		*river,sea*	PE, LDPE, PET
	Other	n.a.	n.a			
	TOTAL SECONDARY SOURCES		**n.a.**			

Table 8-2 Best guess on probable shares to sea from the different microplastic sources

Source group		Upstream tonnes	Pathway to sea	Probable share to sea*	Fraction to sea, tonnes
Consumer products, all		40	drain, past STP	small	4
Commercial products, all		100	drain, sea	medium	50
Transport spill		250	to sea	large	225
Production discharge		200	to drain or sea	large	180
Ship paint		330	sea, seaside,	large	297
Marinas		400	sea, seaside	large	360
Building repair		270	sewer, dump	medium	135
Laundries		100	drain	medium	50
Household	Laundry	600	drain past STP	small	60
	Dust	450	drain, air	small	45
City dust outdoor	Road paint	320	sewer,air	medium	160
	Exterior paint	130	sewer, air	small	13
	Tyre dust	4500	sewer,air	medium	2250
Indoor city	Dust	200	sewer, air	small	20
Illegal dumping, paint		100	soil, sea	large	90
Biowaste		336	soil, water	small	34
Paper recycle		60	water	large	54
WEE and ELW		10	air, water	medium	5

small= 10%, medium 50%, large 90%

9. Knowledge gaps and proposal for further studies

9.1. Overall knowledge gaps

Micro plastic pollution is a relative new environmental challenge. This pre-study has estimated both primary and secondary sources for this pollution. However, we have based the estimates on several assumption and data of poor quality. It is thus important to regard the results just as a first indication of sources.

In order to obtain a better understanding of the issue of microplastics and develop better estimates on the different sources, we need:

- As a first priority, more elaboration on the definitions of microplastics and criteria for what is microplastics, including a definition of "solid particles". In this report, we have stressed this issue. Read more in Annex B.
- In addition, we need a better overview of all kinds of particle sizes, even nano particles and particles larger than 5mm. Such an overview can also serve as basis for a better understanding of degradation processes.
- In order to track the sources for microplastic pollution, more information about the particles found can add value. Further classification according to polymers, shape etc. can be useful.
- Within waste management and mass flow analyses, we normally base the studies by weight figures. However, studies related to microplastics and beach clean- ups often quantify by numbers of particles/ items. In order to develop mass flow analyses, it is thus a need for quantification also directly by weight, or by size ranges/volume in order to allow weight estimates.
- Researchers and authorities often focus on hazardous substances. Several studies, also relevant for microplastics do thus not cover the micro plastic issue. Often studies or management efforts on plastic related chemical micro pollutants are measuring concentrations of different plastic additives and break-down products, with no mention of what now emerges as the elephant in the room; the plastic particles themselves. In order to obtain better data and a better understanding, in general, we need a multidisciplinary approach.
- For many microplastic sources there is no information available. A policy to consider microplastic as a 'hazardous substance', just as toxic substances, has internationally been suggested for plastic waste[253], and would rapidly improve monitoring and reporting if applied.

The most difficult aspects to understand are the pathways and the processes from the littering, losses, emissions and/ or the discharges take place on shore to the plastics that reach the ocean and further pathways in the ocean, including defragmentation, biodegradation and sedimentation. However, since these topics are not part of this report,

[253] Rochman, C. M., & Browne, M. A. (2013). Classify plastic waste as hazardous. Nature, 494(7436), 169-171.

we do not elaborate on these important gaps in this report. Instead, below we will focus and list key gaps of knowledge related to the assessments of the most important microplastic sources described in this report, e.g. key figures needed as a follow- up of this report.

9.2. Knowledge gaps and proposals related to primary sources

Table 9-1 Knowledge gaps and proposals related to primary sources

Source	Knowledge gap	Proposed further study
Tyre dust	Share and type of plastics	Analyses of tyre materials and tyre dusts, incl. how to group tyre dust/ particles in the microplastic/ polymer particle framework. Such a study can be combined with dust from asphalt, at least asphalt dust that to a certain extent also contains polymers.
Paint	Content of polymers	Analyses of paint and paint emissions, during life cycles, incl. how to group paint emissions and particles in the microplastic/ polymer particle framework, case studies on exterior paints, emissions from marinas/ shipyards and road paint.
Textile fibers	Emission data from textiles in use and by washing	Analyses of textiles used and washed in Norway, and dust/ fibers emissions from textiles and losses of fibers during use and washing of textiles
Different sources via rivers and storm water/ sewage	Microplastic entering the ocean from rivers, storm water and sewage	Analyses of microplastics entering the ocean via main rivers, storm water/ sewage systems Analyses of microplastics removed at the sewage plants, their disposal and the risk for remobilization of microplastics
Production spill	Loss of granulates and regranulates	Mass flow analysis of granulates and regranulates, incl. transport operations and physical handling throughout the value chain.
Polymer use in oil and gas drilling	Polymer discharges	Analyses of the use of polymers use in oil and gas drilling and disposal of the waste.
Consumer products	Content of micro beads and polymer particles	Analyses of the use of microbeads and polymers in consumer products whereby the polymers end in sewage system.
Waste handling	Emissions from plastic waste washing plants and paper recycling	Analyses of plastics used as coating to paper products and plastics entering paper recycling plants and possible losses of microplastics from paper- recycling plants. Analyses of microplastic emissions from plastic recyclers and their washing plants
Products in use	Abrasion	Analyses of abrasion from key plastic products in use, e.g. generation of micro plastics
All products	Assessing additives in key applications	Analyses of key additives used in the most frequent primary sources and their properties in water.

9.3. Knowledge gaps and proposals related to secondary sources

Table 9-2 Knowledge gaps and proposals related to secondary sources

Source	Knowledge gap	Proposed further study
Fisheries and aquaculture	Loss of fishing equipment and waste discarded	Material streams of equipment containing plastics, focusing on losses Waste generation and waste disposal analysis; focusing on waste discarded in the ocean vs. delivered in harbours
Shipping and offshore activities	Loss of equipment and waste discarded	Material streams of equipment containing plastics, focusing on losses Waste generation and waste disposal analysis; focusing on waste discarded in the ocean vs. delivered in harbours
Onshore littering, and storm water/ sewage	Macro plastics from rivers, storm water and sewage	Analysis of macro plastics entering the ocean via main rivers, storm water/ sewage systems Analysis of macro plastics removed at the sewage plants, their disposal and the risk for remobilization
Macro plastics in the ocean from foreign sources	Imported macro plastics by sea	Study on macro plastic emitted from other countries, Germany, UK, Sweden and Denmark, gross volumes, types, and applications.

A. Appendix References

a. References/ Literature

All references/ literature are listed in the text of this report.

b. Other references/ personal Communications

Photos: The authors, except 6.2: E. Mariussen, 6.3, 6.4: Wikimedia commons, 7.1 A-L. Bekken. Front page photo: Erik Skabo "Polymer marine pollution", Lofoten, Norway

The list below comprise the name of persons who has contributed to the report by phone or mail.To a certain extent, these references are also listed in the text of this report.

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B. Appendix Definitions of microplastics

a. Microplastic synonyms

The marine pollution literature uses the word "microplastics". The title of this report also uses the word "microplastics". However, plastics are based on polymers, again based on monomers. Monomers and polymers are used in many other applications than purely what would in common language be named "plastics." In the plastics industry the term microplastic is not used when discussing upstream production. The wording would often have to be "polymer particles". Also within pollution management, "microplastic" is not yet a commonly used term. For example, in air quality studies the term "synthetic organic particles" (SOP) would cover the same kinds of micro sized polymer particles. In Norwegian pollution legislation, microplastic emissions are not regulated directly with reference to a specific term, but in air pollution within the broader category "dust", and in water pollutions maybe regarded as dry particulate matter or suspended matter. This would be the case in most other countries as well, but a few initiatives to regulate microplastics do exist[254].

In this report we will mostly use the expression "microplastics" as a broad and general term without trying to refine it further. However, we stress the need to expand the scope of such micro particles to (several) solid polymer particles. In this way all kinds of particles in the marine environment can be grouped in a consistent way.

b. Less than 5 mm

"Microplastics" as a term is quite new in the scientific literature about marine pollution[255]. The term has appeared useful to identify an emerging pollutant in the seas, the smallest fractions of plastics in the marine litter. Such fragments can be all kinds of shapes (e.g. irregular fragments, fibers, spheres, beads, pellets, and sheets) and would often in common language be named "hardly visible plastic pieces", and the smallest ones even "plastic dust". We are talking about sizes, for example, the width of a human hair or a grain of sand.

There are several reasons why such microplastics distinguish themselves from plastic macro debris and deserve their own term and attention, except for the visual size difference. Among them are:

a) Microplastics often appear in broken or unidentifiable fragments, thus their sources are even more cryptic than those of large plastic debris.

b) Small particle sizes influence physical attributes and how the particles behave in the sea, compared to larger items. A classic example would be that smaller particles would sink much slower than a larger object with identical specific gravity. The often turbulent runoff pathway or the ocean small particles would hardly sink at all but get transported around.[256].

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[254] Policy initiatives have been gaining momentum at municipal, state, and national levels in the U.S. In June this year Illinois passed legislation banning microbeads (microplastics used in cosmetic products that enter the environment through wastewater), with similar legislation pending in New York and California, and recently introduced in the U.S. House of Representatives. Source: Science Daily (2014), Webpage http://www.sciencedaily.com/releases/2014/07/140710141630.htm.

[255] Reviewed e.g. by Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. Environmental Science & Technology, 46(6), 3060-3075. doi: 10.1021/es2031505

[256] E.g. particles from city surfaces are suggested to follow stormwater rather than fall out to sewer sediments when they are smaller than 0.1 mm.

c) Also the chemical properties could be very much affected at small size, the well-known extreme of this is nanoparticles. The property defining size probably lies at 1µm. This is about the size where the particles exhibit colloidal properties. I.e. cease to precipitate. The high surface to volume ratio of small particles gives them a high potential for leaching and uptake of chemicals.

d) Small particles also have biological implications, getting small enough they can pass protective barriers and penetrate deeper into the organism.

A suggested and much supported practical definition is hence now that all plastic fragments less than 5 mm should be included in microplastic surveys. Larger plastic items should then not be counted in among the microplastic in a survey ment to be comparable to other studies, but be clearly distinguished as another size class. The size range downwards should be covered as far as practically possible. Normally for most practical sampling this would include the micrometer-range. Nanoscale polymers would anyway be called nanoparticles in the pollution literature, but it is important to acknowledge that they exist as part of the microplastics. Nanoscale polymers are often mentioned as just nanoparticles in the pollution literature, or thought to be dissolved molecules. They would also be extremely hard to sample and separate in the field for most practical purposes. The nano unit starts physically at below 1 micro meter. Nano behaviour is another scale model, as particles change their behavior physically and biologically at a certain size.

The micro and other plastic particles can be classified as follows[257]:

Size	Name of particles	Typical size of aquatic organisms	Plastics from industry
<25 mm	Macro plastic particles	Fish, shellfish, mussels	
5-25 mm	Meso plastic particles		Granulates
1-5 mm	Larger microplastic particles		
<1 mm	Smaller microplastic particles	Plancton	Plastic particles in cosmetic industry

c. Solid plastic fragments

Another important characteristic of microplastic pollution is that it in general is persistent in the environment. Actually, the major concern of marine plastic litter is that it is not easily degraded, and "may persist for several hundred or thousand years in the marine environment". However, not all microplastics are non-degradable. Polyethylene and polypropylene in the presence of Ozone and UV will certainly degrade. It may take some

[257] According to Nova Institute, partly based on JRC 2013 and STRAP

years, but in the end, they will be degraded to molecules that can be metabolised by bacteria[258].

To be considered microplastic pollution, the plastic type needs to be present as solid pieces of material and not, for example, dissolved chemical molecules. This means that softer and more easily dissolved plastic-like materials, such as waxes, oils, or liquids are normally not counted as microplastics. However, an important point is that if they contain or give away microplastic particles, which are solid and persistent for some time during usual environmental conditions they might still fall under the term.

Manufacturers of some plastics claim they are biodegradable, compostable or Oxo-degradable on shore. Because these plastics are often suggested as substitutes for more persistent plastics, their properties in the marine environment are described as a special case in chapter 7.8 in this report.

d. Microplastic can be all sorts of synthetic polymers in the "plastics family"

Plastics are (mostly) synthetic polymeric materials, and they are indeed a big family of very common materials in widespread use. Some examples are given in the table below. The major types are the thermoplastics (such as polyethylene) which in production are melted into the desired shape, and can be reused and reshaped if melted again.

Thermoset plastics (such as polyester, vulcanized rubber, melamine and epoxy), on the other hand, are more rigid and durable but are stuck in their final structure and cannot be re-melted. They are more common in commercial and industrial uses.

In addition to plastics being used in "plastic products", it is more and more common to add polymers to improve properties of other materials such as paper, cosmetics, coatings/ paint, concrete, tarmac for asphalt, or textiles. To which degree these polymers can end up as microplastics/ polymer solid particles is still unclear.

Polymers can be used as basis, often together with additives, for production of solid plastics, for example PE, or used, solid particles, in liquid products, called suspensions and emulsion, as input material for a long list of different products, for example coatings, ink, mud for oil drilling etc. Several paper products, like magazines, are coated with polymers. In addition, the ink is based on polymers. Polymers are also used in bitumen and thus asphalt and also in some kinds of rubber: About 15 million tonnes of rubbers are produced annually, two thirds of that is synthetic, e.g. polymers, a type of artificial elastomer mainly synthesised from petroleum by-products. While natural rubber comes from latex of *Hevea brasiliensis*, the synthetic rubbers include EPDM (Ethylene Propylene Diene Monomer), silicone and polyurethane e.g. used in asphalt: SBR (Styrene Butadine) and SEBS (Styrene Ethylene Butylene Styrene Copolymer).

All plastic materials are made up of mixtures of macromolecules of different chain lengths and thus different molecular weights. Their "backbone" can be made of materials of

[258] See for example Zheng, Y., Ynaful, E. K., & Bassi, A. S. (2005). A review of plastic waste biodegradation. Critical reviews in Biotechnology, 25, 243-250. or Albertsson A.C., Andersson S.O., & Karlsson S. (1987). The mechanism of biodegradation of polyethylene. Polymer Degradation & Stability, 18, 73-87.

petroleum carbon sources or biological sources. Often plastics have several additives, and also are mixes of different plastic types. Plastics are sometimes made of a single monomer type, for example when ethylene terephthalate monomers are polymerized to poly ethylene terephthalate (PET), a homopolymer. Copolymers are made by polymerizing different monomers in the same chain. Plastics can also be a blend of different plastics mixed together after the polymerization. They can also be mixed or polymerized with other materials, and hence the distinction of plastics from for example chemical groups such as synthetic rubber, synthetic waxes and synthetic coatings is not always straightforward.

Global plastic production is estimated by the plastic industry to 300 million tonnes in 2013[259]. These figures do not comprise all polymers produced and used by industry. However, the figure includes thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants and PP-fibers. Not included, according to this PlasticsEurope survey are PET-, PA- and polyacryl-fibers. The study of the plastic industry seems to tend to concentrate on the production of their members within "the plastic family", not comprising for example producers of silicone and cellulose. However, polymers are also produced within other industries.

To decide what is microplastics vs. not microplastics, statistics can be another source of information. According to EUROSTAT statistics, plastics belong to the group code 2016. According to EUROSTAT, latex and synthetic rubber belongs to another group, e.g. 2017. Probably, statisticians did not have microplastics in mind when developing this system. Statistics *can thus be a useful tool, but will probably not give an exact answer to all "microplastic*" sources.

In order to improve the understanding of "Microplastics", other alternative wordings can be used, for example "Synthetic organic particles" (SOP), or polymer particles

e. Microplastics must be distinguished from other micro particles

If you have a close look at a dust sample, a sample of water, sediment or filtrate from the sea many kinds of microscopic particles turn up. Commonly you will see: whole and pieces of living or dead plankton and bacteria, mineral particles and different fragments of plants or macro algae. Also litter fragments of human origin other than plastics are present: for example paper fibers, non-synthetic textile fibers (e.g. wool and cotton), glass, soot (black carbon) and asphalt. Several techniques have been developed to sort the plastics from other materials, and also to determine the exact plastic type[260] and fingerprint its general origin.

In this report, we have attempted at giving weight only to sources of particles which are identified as plastics/polymers, that is, we have not given mention to studies of unidentified particles.

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[259] PlasticsEurope, personal communication
[260] Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. Environmental Science & Technology, 46(6), 3060-3075. doi: 10.1021/es2031505

C. Appendix Plastics and additives

a. Plastics

In order to illustrate what is regarded as plastics the following description from Wikipedia gives an overview:

"A ***plastic*** *material is any of a wide range of synthetic or semi-synthetic* organic *solids that are moldable. Plastics are typically organic polymers of high molecular mass, but they often contain other substances. They are usually synthetic, most commonly derived from petrochemicals, but many are partially natural.*

Most plastics contain other organic or inorganic compounds blended in. The amount of additives ranges from zero percentage for polymers used to wrap foods to more than 50% for certain electronic applications. The average content of additives is 20% by weight of the polymer. Fillers improve performance and/or reduce production costs. Stabilizing additives *include fire retardants to lower the flammability of the material. Many plastics contain fillers, relatively inert and inexpensive materials that make the product cheaper by weight. Typically fillers are mineral in origin, e.g. chalk. Some fillers are more chemically active and are called reinforcing agents. Since many organic polymers are too rigid for particular applications, they are blended with* plasticizers, *oily compounds that confer improved rheology. Colorants are common additives, although their weight contribution is small. Many of the controversies associated with plastics are associated with the additives.*

Plastic types[261]

According to international standards, plastics are split into seven categories/ plastic types/ polymer groups. Normally plastics are recycled type by type, but some mixes are acceptable, e.g. PP and PE, while other mixes are not possible.

Table 9-1 Plastic types and symbols, American Chemistry[262]

Code	Plastic type	Abbreviation
	Polyethylene terephthalate	PET PETE
	High Density Polyethylene	HDPE
	Polyvinyl chloride	PVC

[261] 261 Økt utnyttelse av ressursene i plastavfall, Mepex rapport utført for KLIF, 2012
[262] Workshop of the technical WG for the development of end-of-waste criteria- waste plastics, European Commission, DG JRC, 2011

Code	Plastic type	Abbreviation
4 LDPE	Low Density Polyethylene Linear Low Density Polyethylene	LDPE, PE-LD PE-LLD
5 PP	Poly-propylene	PP
6 PS	Polystyrene	PS
7 OTHER	Acrylonitrile butadine styrene Polyamide Polymethyl methacrylate Polyurethane Styrene-acrylonitrile	ABS PA PMMA PUR SAN

All the plastics in the table can be made from fossil resources or from renewable resources. If PE is made from renewable resources, the PE is often called Green PE.

In addition, there is also a long list of biobased (such as PLA, TPS and PHA) and/ or biodegradable plastic types (such as PCL, PBSU, PVOH) now entering the markets. New materials make it more challenging to sort the plastic waste; in addition biodegradable plastics can also harm recycling of traditional plastics[263]. PHA and PLA are both mentioned in chapter 7.8.1.2 regarding their degradability in the ocean.

b. Plastic additives

Looking at marine littering, common additives of plastics are interesting both as potential tracers of microplastics[264], and important because they might constitute a pollution problem if/when they are released to the environment and taken up by organisms.

Plastic products and plastic waste contain different additives in order to obtain the wanted properties of the products. As part of the End of Waste process for plastics, **the EU Commission** elaborated in brief on the issue of additives and hazardous substances in plastic waste and also explained the link between end of waste criteria and different EU legislation:[265]

[263] Mepex (2013), Resource efficient recycling of plastic and textile waste
[264] Personal Communication Arp, Norwegian Geotechnical Institute
[265] European Commission, DG Joint Reserach Centre, mail correspondance to all EoW stakeholders by A. Villanueva, 11.05.11

Most additives of the original waste plastic, except e.g. lubricants or catalysts, are <u>not</u> consumed, altered or degraded during the melting process of mechanical recycling (much unlike glass or metal recycling), so these are kept and found in the pellets.

There are hundreds of additives in the EU market, and their presence in the plastics can vary largely, from a few percentages and up to 50-60%. Some of them are sought after in recycling, as they are much needed in the recycled product (e.g. stabilizers, hardeners, plasticizers, structural fillers). Some of them may have no function in the recycled product (UV absorbers, flame retardants) or need correction measures (odor, color). In most cases, re-adjustment of additives is needed in the manufacture of recycled plastic products.

More than 99% of the additives appear to have no environmental or health risk. The recycling of these well identified, no-risk polymers and additives shall be encouraged. Currently, only very few problem substances used in/as additives have been identified as bearing environmental and/or health risk, notably:

- *Bisphenol A (curing agent in polycarbonate and epoxy resins)*
- *Low molecular weight phthalates (plasticizers): DEHP, BBP, DBD, DIBP, but not high molecular weight ones such as DINP and DIDP.*
- *Halogenated flame retardants*
- *Toxic heavy metals (colorants and stabilizers): Cadmium, Chromium6, Lead and Mercury.*

Some of these substances have been voluntarily phased out by the industry, and they are present as legacy but are not being re-introduced in the plastic cycles through virgin plastics. The presence of these substances in waste is currently handled via specific legislation, essentially WEEE and ROHS, and to a certain extent REACH (e.g. Annex XVII on restriction of uses of recycled material). The presence of these substances in plastic products is handled by REACH (and CLP for labeling), the POPs Regulation, and specific food contact legislation for this type of use. Should these substances be present, REACH is to ensure the provision of environment and health information through the supply chain. Once the plastic products are used and become waste, this information chain is broken. Reprocessors and especially converters have to re-establish the information chain, in the first place by characterizing thoroughly the recycled plastic output. This characterization is also essential for the identification of residues of materials that were in contact with the plastic during its use (e.g. solvents), or substances are added/formed during re-processing (e.g. flame retardant reaction products). Spectrograph or chromatograph - like characterization is essential and commonplace in sensitive applications such as food contact.

The main objective of a Regulation on EoW is to facilitate the recycling of plastic of high quality. It is also to clarify and harmonies the characteristics required for EoW plastic, and the legislative background for operation of recyclers and authorities once it enters into force. The EoW regulation shall <u>not</u> be used to duplicate existing control mechanisms, although it shall complement these mechanisms where they would appear not to provide sufficient safeguards under precautionary aspects specific to recycled material. Ideally, the EoW regulation shall be shaped as simple as possible, restricting the presence of non-plastic material, and clarifying for all parties the application of the boundary existing legislation for waste (WEEE, ROHS) and *non-waste (REACH, POPs). Emphasis shall be placed in the EoW regulation on operational quality control of the output material.*

The OECD[266] has given the following general introduction to the presence of additives in polymers:

Frequently, the polymer itself does not possess the full range of required properties and the majority of plastics will have undergone some form of compounding process before their conversion into finished artefacts.

Additives used for performance enhancement
The main functions of additives used for performance enhancement are listed below.
Fillers: Fillers are inert materials which reduce polymer costs, improve processability and can be used to improve the mechanical properties of the resulting plastics material. They are solids, which are incorporated into polymers but which remain as a separate phase.

Plasticisers: Liquids or waxy (i.e. low melting) solids which fall into two general classes: Permanent plasticisers enhance the flexibility of a plastics material and/or inhibit the embrittlement of the material at low temperatures; these substances are expected to survive the service life of the product in which they have been incorporated and so require a low propensity to migration. Latent plasticisers improve the processibility of plastics material during compounding and melt fabrication. They are subsequently removed during post-fabrication oven drying.

Antioxidants: A range of chemicals such as amines, phenols, phosphates etc. are used to inhibit degradation of polymers such as polyethylenes, polypropylenes and styrenic materials during the life of the product.

Coupling agents: Silane and titanate compounds are used to improve the bond between polymer matrices and mineral fillers and fiber reinforcements.

Colourants: A wide range of dyes and pigments are used throughout the industry.

UV & other weathering stabilisers: Generally these are benzo derivatives. However, polymers with good weathering properties such as PVC are sometimes blended into other polymers. They are mainly incorporated into plastics for applications requiring long life, such as building products, automotive and other engineering components. As in the case of permanent plasticisers, the stabilisers are required to function throughout the life of the product.

Polymeric impact modifiers: These are often elastomers or elastomer/polymer blends, used to retard or inhibit brittle fracture by absorbing the crack-initiating energy. By definition, the elastomers and the matrix polymers may not be fully compatible.

Anti-static agents: The purpose of these substances is to inhibit the development of static. In general, these are conductive powders and metal flakes but intrinsically conductive polymers may also be used in certain circumstances.

Flame retardants: Key application areas include packaging, the electrical and the electronic industries. Compounds based on halogens, boron and phosphorous are used to reduce the risk of ignition and retard combustion.

Preservatives: Fungicides and bacteriostatics are occasionally used in plastics which may be expected to be exposed in service for long durations.

Additives used as processing aids
The main functions of additives used as processing aids are listed below.

Curing agents Peroxides, amines and organotin compounds are used to assist in the curing of thermosetting materials. In some cases there is a need to retard curing and amines may be used for this purpose.

Blowing agents Plastics materials are often used in a cellular form. The cells may be formed either by direct gassing or, more commonly, by the use of chemicals or solvents which release copious quantities of gas on heating. Cellular plastics are used as lightweight foams for packaging and thermal insulation; in higher densities the cellular structure enhances the rigidity of polymers.

Heat stabilisers Organic or organometallic compounds used to reduce the degradation of PVC and other vinyl materials subject to degradation during processing and conversion into finished products.

[266] OECD (2009) OECD SERIES ON EMISSION SCENARIO DOCUMENTS Number 3. EMISSION SCENARIO DOCUMENT ON PLASTIC ADDITIVES

Slip promoters or Lubricants:
Improve surface lubrication during processing and use

Viscosity aids: Materials which are used to regulate the viscosity of PVC- plasticiser solvent mixtures during processing. They are themselves polymers.

Because there exist several thousand plastic additives, the ones most relevant to health and environmental effects should have focus here. Rochman *et al.* (2013[267]) is referring to their own unpublished results that that at least 78% of priority pollutants listed by the EPA and 61% listed by the European Union are associated with plastic debris. Some are ingredients of plastic, and others are absorbed from the environment.

Similarly, of the Norwegian High Priority Chemicals[268] (should be phased out within few years).A set of criteria has been drawn up for identifying priority substances. These include substances that are persistent and bioaccumalative, that have serious long- term health effects, or that show high ecotoxity.[269] There are nine plastic additives on the list; some of them are described above.

- *Bisphenol A(BPA)*
- *Lead (Pb)*
- *Brominated flame retardants (Penta-BDE, Okta-BDE, Deka-BDE, HBCDD og TBBPA)*
- *Dietylheksylphtalat (DEHP)*
- *Cadmium (Cd)*
- *Short chained chlorinated paraffins (SCCP)*
- *Chromium (Cr)*
- *Medium chained chlorinated paraffines (MCCP)*
- *Pentachlolorophenol (PCP)*
- *Mercury (Hg)*

Among other historically infamous POPs often related to polymer products are PCB, HBCD and nonylphenols. Among important emerging pollutants being of plastic related origin, and which will turn up in some microplastic particles, are perfluoro alkyl substances and organophosphorous flame retardants. [270]

Lattuati-Derieux et al (2013) shows by analysis typical chemicals and additives emitted by both new plastics and historical plastic items. Lithner et al. 2011 identified and compiled the environmental and health hazard information of chemicals used in 55 common plastic polymers[271]. Several plastic ingredients and building blocks, i.e. monomers, can be hazardous by themselves, but high volume additives are also given a mention:

"Several thousand different additives exist for plastic polymers. The additives are mixed with the polymer, creating a compound which is processed to a plastic product. The use of additives is not evenly distributed among the different plastic types. PVC requires by far the most additives of all plastics types, alone accounting for 73% of the world production of additives by volume, followed by polyolefins (polyethylene and polypropylene) (10% by

[267] Rochman, C. M., & Browne, M. A. (2013). Classify plastic waste as hazardous. Nature, 494(7436), 169-171.
[268] (http://www.miljostatus.no/tema/Kjemikalier/Kjemikalielister/Prioritetslisten/)
[269] http://www.environment.no/tema/Kjemikalier/Kjemikalielister/Prioritetslisten/
[270] Mepex (2011) Økt utnyttelse av ressursene i plastavfall (In Norwegian) Environmental Agency report TA-2956/2012
[271] Lithner, D., Larsson, Å., & Dave, G. (2011). Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Science of The Total Environment, 409(18), 3309-3324.

volume), and styrenics (5% by volume) (Murphy, 2001). PVC for instance needs heat stabilisers to prevent the polymer from degrading during processing, and needs plasticisers to become flexible. Polypropylene is extra sensitive to oxidation and requires large amounts of antioxidants and UV-stabilisers, as does polyethylene but to a lesser extent (Zweifel, 2001). Some of the most hazardous additives include some brominated flame retardants (e.g. tetraBDE and pentaBDE), some phthalate plasticisers, and lead heat stabilisers. Since additives are not usually bound to the polymer matrix, are of lowmolecular weight, and may be present in large amounts, they often account for the major leaching and emissions of chemical substances from plastic materials."

The additives can to a certain extend be linked to different polymers and applications, see table 9-2 below for some examples from plastics produced or used in Norway, and hence relevant for present marine littering. However, in this pre-study we have given the priority to find and describe the sources of microplastic pollution. In further research, detailed information about the plastics from key sources should be examined further. This will often involve information from the suppliers of the products, the compounders and the producers of the plastics. Alternatively, the Norwegian product register also can be a source for such information.

Table 9-2 Examples on contaminants originating from plastic materials found in Norway. [272]

Application	Polymer Code	Polymers	Additives
Beverage bottles	PET	Polyethylene terephthalate	BPA, Cr, Sb, Ti
Plastic can for soap	HDPE	Polyethylene, high density	PCB
Fleece jacket	PPPET	Polyethylene terephthalate	SCCP,MCCP,Br, Sb, Ti
Water tubes	PVC	Polyvinyl chloride	Cu,Pb
Sticker film	LDPE	Polyethylene, low density	SCCP, MCCP
Beverage bottle lid	PP	Polypropylene	PCB,Cr,Cu
Furniture foam	PU	Polyurethane	BFR, OPFR
Styrofoam buoys	PS	Polystyrene	HBCD[273]
Sports apparel	PS	Polystyrene	Triclosan
Fishing nets	PA	Polyamide (nylon)	UV-stabilizers

[272] Based on: Amlo S and K . Bakke (2010) Kartlegging av nyere fraksjoner av farlig avfall i bygg. Identification of new building components that should be classified as hazardous waste. Report. Norwegian Environment Agency., Ottesen R.T. (2010) Innhold av kortkjedete klorete parafiner (SCCP), mellomkjedete klorerte parafiner (MCCP), Bisfenol A og metaller i forbrukerprodukter av plast og gummi. Report (In norwegian). NGU. as well as Schulze, P-E. (2004) mapping of selected priority POPs in Norwegian production. Webpage:
http://miljojuss.no/getfile.php/Bilder/Forurensing/Motgift%20Oversikt%20over%20norske%20bedrifter%20som%20selger%20eller%20bruker%20ilj%C3%B8gifter%20pr%202004.pdf
273 Rani, M. Won Joon Shim Gi Myung Han , Mi Jang , Young Kyoung Song and Sang Hee Hong (2014) Hexabromocyclododecane in polystyrene based consumer products: An evidence of unregulated use. Chemosphere, 110, 111-119.

Vinyl flooring	PVC	Polyvinyl chloride	Phtalates

D. Appendix Details on methods

a. Literature study

The work started with a search for scientific articles and other reports giving credible documentation on microplastic sources. Starting with new reports and reviews mentioning "microplastic pollution", or "small fragments of marine litter" we did the usual tracking backwards and forward until the same references turned up repeatedly as a sign that the most important works were covered by the search.

To make sure we extended the search to all relevant microplastic sources, and including search terms also beyond the traditional marine pollution literature if necessary, we made an *ad hoc* conceptual model for thinkable microplastic pollution sources. This was based on the authors' experience with sources and mass flow with other micro pollutants. This model was used as a checklist (see chapter 5.8 and table 5-3).

Data was compiled in the fact sheet described below and compiled in chapter 6. This search also illustrated loopholes and knowledge gaps summarized in chapter 9.

b. Gather information from other relevant sources

In the second phase, we searched other grey (e.g. not scientific literature) sources and made interviews in different industries for additional information in order to close the data gaps and obtain a basis for further calculations and assessments. Data has been compiled in the fact sheet described below and compiled in chapter 6.

c. Calculations and assessments

In the third phase we assessed the data and made simple calculations in order to quantify the sources of pollution. We have taken a mass flow approach, and ideally the sources would then be estimated based on real data of national use of a material combined with a reliable emission factor for each source based on a statistically reliable dataset. Most often this is not available for microplastics. Anywhere possible we have still tried to give estimates even if some assumptions and default values have to be included. These are clearly stated, so that the calculations can be refined as the knowledge on each source progresses.

Because this report is a pilot study, there has been no possibility to go out in the field and collect our own representative data based on e.g. sampling or interviews in whole sectors. All calculations are hence based on existing knowledge already accumulated by key references. We have given the following priority when choosing the data sources for the estimations:

1. Exact knowledge about use and emission factors in Norway.

2. Exact knowledge from neighbouring countries or Europe, if possible, to adopt.

3. Upscaling to national level from exact knowledge in single emission cases.

4. Building a simple scenario using default emission factors published and approximate volume of use knowledge.

5. Different approaches of back calculating from environmental data or combining bits and pieces of data to get a loose idea about emission level.

d. Fact sheet for microplastic pollution source

As a tool and checklist for this report, partly also for the dialogue with stakeholders in the market, we have used a standard fact sheet to describe each group and even some key sub groups of relevant source of microplastic pollution. The fact sheet lists all information wanted. However, at this stage and within the framework of this project, much of the data wanted is not available, neither from literature nor from industry.

Bellow follows a template-fact sheet used in the project.

Criteria	Description
General description of source	
(Possible) reason for pollution	
Process; Where in life cycle /Pollution point	
Number of sources in Norway	
Sources outside Norway	
Pollution flow to the Norwegian oceans	
Degradation process	
Plastic types	
Additives	
Listed hazardous substances found	
Physical properties -persistence -melting point	
Size of particles, mm	
Shape of particles	
Weight of particles	
Producers of plastic material	
Product producers	
Product distributors	
Plastic production or plastics used, tonnes	
Key assumption for calculating pollution	
Total weight of pollution per day	
Annual pollution	
Actions taken to reduce pollution	
Trends/ outlook	
Key literature sources	
Other references	

The data obtained is used as basis for the description listed in chapter 6. The open spaces from this exercise indicate data gaps, summarized in chapter 9.