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Sources of microplastics relevant to marine protection in Germany

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Sources of microplastics relevant to marine protection in Germany

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Executive summary

Scientific studies have shown that the litter found in oceans and inland waters is dominated by plastics. Besides large items such as plastic bottles and bags, the occurrence of microplastics has also been verified in water bodies, sediments and on the beaches of the world's oceans. Litter in the marine and coastal environment is known to have negative effects in 663 species. More than half of these ingest or become entangled in plastic debris. Not only larger plastic objects but also particles and fragments less than 5 millimetres in size can lead to mechanical injuries of the alimentary tract, prevent digestion and block the intake of food. Moreover, their components may be toxic or develop endocrine effects. Hence there is also a risk of pollutants accumulating in the marine food web. Furthermore, microplastics can act as a transport medium for pollutants, invasive species and pathogens.

These alarming results prompted the Federal Environment Agency to commission a study to produce a first approximation of the amounts of microplastics used in cosmetic products on the market in Germany and the European Union, conduct research into further areas of application for microplastics and determine their amounts of use, and identify other sources of microplastics and estimate their quantity. The nova-Institute gathered the relevant data by comprehensively analysing available literature and conducting telephone interviews. A distinction was drawn between primary and secondary microplastics. Primary microplastics are directly manufactured as microscopic particles that are used in cosmetics and other applications. Secondary microplastics are fragments of macroscopic plastic materials which arise, for instance, through the fragmentation of plastic bottles or abrasion of tyres and textiles.

Initial estimates indicate that every year approximately 500 tonnes of primary microplastics composed of polyethylene are used in cosmetic products in Germany. The authors put the quantities used in detergents, disinfectants and blasting agents in Germany at less than 100 tonnes per year each, whereas for microparticles in synthetic waxes they estimate around 100,000 tonnes per year. More accurate figures regarding amounts of use in the various other applications are not available at present, meaning that the total amount of primary microplastics used in Germany cannot be determined.

Fragmentation of plastic debris is the most significant source for the origination of microplastics. According to scientific estimates each year between 6 and 10% of global plastics production ends up as marine litter. Since waste management in Germany is rather advanced, it can be assumed that less plastic debris is ending up in the environment here but reliable data are not available yet. Other sources of secondary microplastics which have hitherto been neglected but which are significant due to their high use are synthetic fibres shed from garments and other textiles during washing, tyre abrasion in road traffic and loss of granulates during the manufacture and processing of plastics.

Microplastics in cosmetic products therefore play a minor though avoidable role in environmental pollution caused by plastic debris. Therefore, to curb microplastic emissions into the environment, and in particular the marine environment, it is not enough to focus on the use of primary microplastics in cosmetic products and other applications. Additional measures which drastically prevent further introduction and cut the overall quantities of plastic litter in the environment are needed – not only in Germany and Europe, but throughout the world.

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Abbreviations

EU	European Union
HELCOM	Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area
IHO	Industrieverband Hygiene und Oberflächenschutz für industrielle und institutionelle Anwendung
IKW	Industrieverband Körperpflege- und Waschmittel e.V.
INCI	International Nomenclature for Cosmetic Ingredients
IVC	Industrievereinigung Chemiefaser e.V.
OSPAR	Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
PA	Polyamide
PC	Polycarbonate
PE	Polyethylene
PEEK	Polyether ether ketone
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoate
PLA	Polylactic acid
PMMA	Polymethyl metharyclate
PP	Polypropylene
PU	Polyurethane
TSG ML	Technical Subgroup on Marine Litter
UBA	Umweltbundesamt (Federal Environment Agency)
WDK	Wirtschaftsverband der deutschen Kautschukindustrie e.V.

1 Introduction

Scientific studies have shown that the waste found in oceans and inland waters is dominated by plastics (Barnes et al. 2009). The United Nations Environment Programme (UNEP) estimates that up to 18,000 pieces of plastic debris are floating on every square kilometre of ocean (UNEP 2006). Yet it would appear that plastics floating on the surface or in the upper water column are just the tip of the iceberg. Around 20 years ago, floating plastic litter accounted for about 15% of the quantity occurring in the North Sea marine environment, while 70% sank to the sea floor and the remaining 15% was washed up onto the coast to join the waste discarded by tourists and other visitors all along the shores (OSPAR 1995). Between 2002 and 2008 plastic debris made up around three quarters of the litter found on Germany's North Sea beaches in the course of OSPAR's regular beach litter monitoring. In the Baltic Sea the MARLIN project found plastic accounted for around 62% of litter on urban beaches and 54% of litter on rural beaches.

Plastics are made by bonding low molecular weight molecules called monomers in different chemical reactions to make high molecular weight compounds known as polymers. Another way of manufacturing plastics is to modify high molecular natural materials (Eyerer et al. 2005). Plastics are classified as thermoplastics, thermosets or elastomers depending on their properties. These materials are usually mixed with other chemicals, fillers or additives in order to create the desired properties and functions for a product. These include plasticisers, adhesives, flame retardants and pigments.

It can take centuries for physical, chemical and biological processes to degrade plastics in the oceans (UBA 2010). Besides large waste items such as plastic bottles and bags, microplastics also occur ubiquitously in gyres, sediments and on beaches, and are frequently detected in marine organisms.

Where possible, deductions are drawn regarding the origin of this marine litter. OSPAR identified 123 typical indicative finds which can be linked to potential sources. For instance, polystyrene debris might be the remains of fish boxes. Residues of fishing equipment can be evaluated according to the type and material of the net, which can be specific to a particular type of fishery. However, the wide range of plastics and their uses makes it impossible to attribute a definite source to all plastic litter in the world's oceans. Polyethylene, for example, is used in microparticle form in cosmetic products, but it is also the world's most produced plastic. Polyethylene waste might therefore come from cosmetic products, but could also originate from numerous other product types (Leslie 2014).

Annex 1 of the Marine Strategy Framework Directive, which was transposed into German law in 2010, stipulates that the properties and quantities of marine litter must not cause harm to the coastal and marine environment (European Parliament & Council 2008). Several indicators were defined to monitor good environmental status. Descriptor 10 on the characteristics of litter in the marine and coastal environment also includes the indicators 'trends in the amount, distribution and, where possible, composition of microparticles (in particular microplastics)' and 'trends in the amount and composition of litter ingested by marine animals (e.g. stomach analysis)' (Krause et al. 2011).

Marine litter is known to have negative impacts on 663 species (CBD 2012). More than half of these ingest or become entangled in plastic debris. Due to their size and ubiquitous distribution in the pelagic and benthic zones, microplastics are bioavailable to the organisms at the bottom of the food web. These ingest food indiscriminately and are consequently particularly affected. Moreover, frequently used plastics such as polyethylene are low-density and therefore float on the surface. This makes microplastics widely available for plankton, other marine biota and the larvae of commercially used fish species (Ivar do Sul et al. 2014).

Like larger plastic fragments, ingested microplastics can lead to mechanical injuries to the alimentary tract, prevent digestion or block the intake of food to the point that the animal starves due to a continual feeling of satiety. In this context, it is not only the microplastics as such that endanger aquatic organisms: besides mechanical injuries and impairments, the components of microparticles can be toxic or cause endocrine disruption (Rochman et al. 2013). In addition, marine organisms swallowing plastic microparticles may potentially ingest higher doses of persistent organic pollutants which have been absorbed to the surface of these microplastics (Teuten et al. 2007). This poses the risk of toxic substances accumulating in the food web and harming a variety of animal species (Cole et al. 2011).

All these aspects need to be investigated further in keeping with the polluter pays principle. At present the available data is sparse and research is therefore urgently needed. In order to communicate the findings to the public, it is also vital to provide an explanation of the specialist terms.

1.1 Definition of microplastics

Experts draw a distinction between primary and secondary microplastics. Secondary microplastics are the result of the degradation and fragmentation of larger plastic pieces, and are caused, for instance, by fibres being washed out of clothing, or by tyre abrasion in road traffic. Primary microplastics, on the other hand, are manufactured directly in microscopic size and used for the industrial production of many consumer goods. These include microplastics used in cosmetics, detergents and cleaning products and other applications such as blast cleaning of ship hulls in dockyards.

The terms 'microplastics', 'microbeads', 'microspheres' and 'microcapsules' have become established in international usage (Leslie 2014). In German the term 'Mikroplastik' is widely used (Focus 2013; Spiegel 2013). On top of this there are innumerable registered trademarks and individual product names. However, in the context of environmental research focusing on marine protection these terms designate substances which have certain properties in common (Leslie 2014): they are solid materials that are insoluble in water; they are synthetic and have a characteristic small size which distinguishes them from other forms of marine litter.

Users of microplastics in the cosmetics industry apply the term to granules which in general are significantly smaller than one millimetre. In marine protection, however, the term microplastics applies to plastic particles with a diameter of less than 5 millimetres (Arthur et al. 2009), while for Browne et al. (2011) the term is used for plastic particles with a diameter of less than one millimetre. Neither of these scientific references gives a minimum limit for the diameter, meaning that the term also includes considerably smaller particles (Leslie et al. 2011). Microplastics is thus an umbrella term defining various plastic particles solely on the basis of their size.

To harmonise the terminology the European Commission is seeking a clear definition. In 2013, the Technical Subgroup on Marine Litter (TSG ML) recommended introducing size classes for plastic debris (JRC 2013). Table 1 below gives an overview of the sizes and terms proposed by the TSG ML, comparing these to the typical dimensions of affected organisms and industrial applications of plastic.

Table 1 Size classes and designation of plastic marine litter as compared to the typical size of affected organisms and of industrial applications for plastic (Source: Authors' own table, based on JRC 2013, STAP 2011)

Diameter of plastic marine litter	English term	German term	Typical size of affected organisms	Typical size of plastic in industrial applications
> 25 mm	macroplastic	Makrokunststoff-teile	vertebrates, birds	pre-products and end products
5 – 25 mm	mesoplastic	Mesokunststoff-teile	birds, fish	pre-products and granules (pellets)
1 – 5 mm	large microplastic particle	Große Mikropartikel aus Kunststoff	fish, crustaceans	granules (pellets)
< 1mm	small microplastic	Kleine Mikropartikel aus	mussels, plankton	microparticles in the cosmetics

	particle	Kunststoff	industry

To avoid the necessary studies on possible impacts being restricted from the outset, neither the Technical Subgroup on Marine Litter nor the basic biological research set a lower size limit for microplastics. For the present the Federal Environment Agency (UBA) has decided to designate as microplastics all plastic particles with a diameter of more than 1 micrometre and less than 5 millimetres. This decision was guided by analytical feasibility: individual particles up to a size of one micrometre can be verified using Raman spectroscopy. The text that follows uses the term 'microplastics' in accordance with this definition.

1.2 Research framework and objective

One application for microplastics is cosmetic products. However, at present there are no data on the quantities of microplastics used in this sector – as is the case for other applications and material flows. This study therefore aims to

- produce a first approximation of the volumes of primary microplastics used in cosmetic products sold on the German and EU markets (Section 3.1),
- investigate further applications of microplastics and determine their quantities of use (Section 3.2)
- identify other sources of secondary microplastics and estimate their volumes (Section 3.3).

The study examines the significance of microplastics in cosmetic products compared to other sources of marine litter, considers the relevance of substitution, as is currently being contemplated by a number of cosmetics manufacturers (Chapter 4) and draws conclusions (Chapter 5).

2 Methodology

This study entailed extensive desktop research firstly to determine the quantities of microplastics used in cosmetic products and other applications and secondly to identify further sources of microplastics and, if possible, quantify these. An initial systematic analysis of literature and documents evaluated the information available in scientific journals and databases. Internet search engines were used to collect conference proceedings, position papers and other publications.

In the course of the work additional market research methods were used to supplement the research results with industrial know-how. As well as telephone interviews and talks with experts, specialist information portals were consulted for collecting, processing and analysing information. In addition, over 30 cosmetics manufacturers and suppliers based in Germany were addressed in writing to obtain real market data on the use of microplastics and their production. More than half of those approached responded to the query. Unfortunately, there was little willingness on the part of the industry to provide concrete data on production quantities or the types of materials used for microparticles. In total, less than 10 replies could be evaluated for the study during the time available. In the following sections, the information is given with source and listed in the bibliography.

Where these methods did not lead to any clear information on the quantities of primary microplastics used in cosmetic products or other applications, or to the identification of secondary microplastics from other sources, the study estimated quantitative data on the basis of clearly presented assumptions and plausible calculations from which conclusions were subsequently derived.

3 Results

Chapter 3 presents the findings of the study. Firstly, it describes the use of microplastics in cosmetic products (Section 3.1), then highlights other applications for microplastics (Section 3.2) and concludes with details of sources of secondary microplastics (Section 3.3).

3.1 Use of primary microplastics in cosmetic products

In Germany around 400 companies in the cosmetics and detergent industry are members of the industry association Industrieverband Körperpflege- und Waschmittel e.V. (IKW). Of these, more than 300 manufacture cosmetic products. According to the associations data, in 2012 cosmetics worth 12.9 billion euros were manufactured and sold in Germany (Figure 1). Hair-care products account for the economically largest market shares (3,055 million euros or 24%), followed by skin and face-care products (2,810 million euros or 22%), decorative cosmetics (1,439 million euros or 11%), oral and dental hygiene products (1,385 million euros or 11%) and women's fragrances (1,055 million euros or 8%).

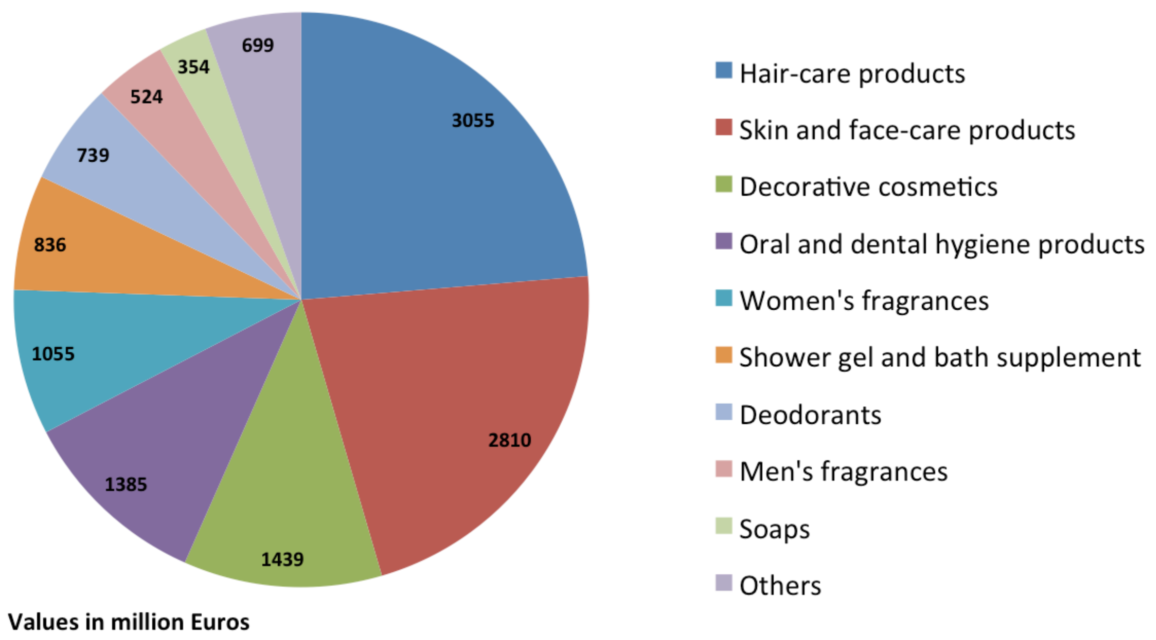

Figure 1 Value of cosmetic products manufactured in Germany in 2012, according to product group (Source: Adapted from IKW 2013)

The IKW says that it does not regularly record production quantities for cosmetics manufactured in Germany (Rettinger 2014). However, the article published in 2009 by Tolls et al. gives some insight, putting total production of cosmetics in Germany in 2002 at 790,000 tonnes. According to the IKW this quantity also roughly corresponds to the volume consumed in the country, since as a rule those cosmetics produced in any significant quantities are not transported over long distances (Rettinger 2014). The article by Tolls et al. states that bath gels, shower gels and liquid soaps, shampoos, cleansers for body care, hair-care products and colorants, skin-care and sun protection products accounted for the largest production volumes for cosmetics manufactured in Germany (Table 2).

Table 2 Production quantities for cosmetic products in Germany in 2002 (Source: Authors' own table based on Tolls et al. 2009)

Product group	Production quantities in tonnes	Share of total production in percent
Bath and shower gels, liquid soaps	175,000	22.2
shampoos	132,000	16.7
Cleansers for body care	118,000	14.9
Hair-care products and colorants	115,000	14.6
Skin-care and sun protection products	109,000	13.8
Dental hygiene products	65,000	8.2
Deodorants	32,000	4.1
Other body-care articles	21,000	2.7
Shaving products	18,000	2.2
Fragrances	5,000	0.6
total	**790,000**	**100**

In 2014 the environmental association Bund für Umwelt und Naturschutz Deutschland e.V. (BUND) published an overview of cosmetic products containing microplastics (BUND 2014). The BUND publication lists manufacturers, product descriptions, specific brand names and the plastics used. Companies named include Body Shop, Colgate, L'Oréal, Procter & Gamble, Rossmann, Schwarzkopf & Henkel und Yves Rocher. The product descriptions and brands include 'Adidas Active Scrub' facial cleanser, 'Clearasil Daily Clear Refreshing' shower gel 'Elmex Sensitive' tooth paste and 'Nivea Stay Real Compact Foundation' makeup. The companies and products named here were selected from the list at random for this study in 2014. A complete list compiled by BUND is regularly updated and can be accessed online[1].

The list classifies products into five groups: Shower and washing gels, face masks/facial cleansers and body scrubs, contact lens cleaner, eye shadow, lipsticks, powder/foundations and

[1] www.bund.net/fileadmin/bundnet/pdfs/meere/131119_bund_meeresschutz_mikroplastik_produktliste.pdf

toothpastes (BUND 2014). The plastics most commonly mentioned in these applications are polyethylene (PE), polypropylene (PP) and polyamide (PA). Also named are ethylene-vinylacetate copolymers (EVA), polyurethane (PUR) and acrylonitrile copolymers with ethyl acrylate or other acrylates (ANM) (BUND 2014). The Institute for Environmental Studies in Holland (Instituut voor milieuvraagstukken, IVM) also verified microparticles of polyethylene terephthalate (PET) and polymethyl methacrylate (PMMA) (Leslie et al. 2012).

The percentage of plastics used in the different cosmetic products varies widely. Some products only need minimal amounts of these ingredients, while others have a plastics content of over 90% (Leslie 2014). Size, form, specific properties and functions of plastic ingredients in cosmetic products are also diverse. Some plastics control viscosity, have a film-forming or opacifying effect. Other plastics act as emulsifiers, adsorbents or abrasives. For instance, under the International Nomenclature for Cosmetic Ingredients (INCI), polyethylene (PE) has film forming and viscosity controlling properties.

Unfortunately, no robust data on the quantities of microplastics used in cosmetic products was available for Germany or the EU before this study was completed. No relevant papers containing concrete figures have been published by the industry, scientific community or authorities on this subject. In this context, Leslie (2014) criticised the fact that there is no overall scientific review of the available information on microplastics in cosmetic products.

The only report published on this topic is by Gouin et al. (2011), which is based on market data for the United States. That report estimates consumption of polyethylene microparticles by US citizens in liquid soaps and shower gels in 2009. Based on a number of assumptions, the authors calculated that around 300 million US citizens used a total of 261 tonnes of such microplastics in cosmetic products. This is equivalent to a per capita consumption of 2.4 mg polyethylene microparticles a day. The information box below describes the methodology behind this research.

Infobox 1: Determining per capita consumption according to Gouin et al. (2011)

1: Market analysis

According to Euromonitor International, around 195 million litres of liquid soaps and shower gels were produced in the US in 2009. Companies using microparticles of polyethylene in such products accounted for 15 percent of the market. This means that up to 29 million litres of liquid soaps and shower gels could contain such microplastics.

2: Assumptions

Based on the market analysis, the authors formulated two assumptions. Ten percent of the products of these companies contain microparticles, and these products have an average microparticle content of 10%. This figure was based on a 1972 US patent for the use in skin cleansers of PE microparticles measuring 74 to 420 µm. This would put use of these microparticles at between 3 and 15% (Beach 1972).

3: Calculation

Based on the market analysis and these assumptions, manufacturers of liquid soaps and shower gels used 0.29 million litres of PE microparticles in 2009. Assuming a concentration of 0.9 g/cm^3 for polyethylenes, this volume corresponds to 261 tonnes of microparticles. With a US population of 300 million, this gives an annual consumption per capita of up to 870 mg PE microparticles, or a daily per capita consumption of 2.4 mg PE microparticles.

Since the authors of this report could find no representative information on the production of microplastics and their use in cosmetic products, they have estimated quantitative data based on transparent assumptions and plausible calculations. The report by Gouin et al. (2011) is the basis for these assumptions. To illustrate the situation for Germany, the authors of this study have made the following assumptions:

Assumption 1: In Germany, 15 percent of companies which manufacture cosmetics in the product group 'bath and shower gels, liquid soaps' use microparticles in 10% of their products, with an average content of 10%. This assumption is in line with the approach taken by Gouin et al. (2011).

Assumption 2: The production volume of liquid soaps, bath and shower gels has remained constant at 175,000 tonnes since 2002. Shower gels and liquid soaps potentially containing microplastics account for around 100,000 tonnes of these. The remaining 75,000 tonnes of bath gels contain no microparticles. This assumption is based on a study by Tolls et al. (2009) and was confirmed by representatives of the IKW (Rettinger 2014).

Assumption 3: German consumption of liquid soaps, bath and shower gels in one year corresponds to the production volume. This assumption was confirmed by IKW representatives (Rettinger 2014).

Assumption 4: The microparticles consist of polyethylene. This assumption is based on the report by Gouin et al. (2011).

The quantity of microplastics is calculated on the basis of assumptions 1 and 2 in a step-by-step process. The following written example from the report illustrates the method: *"Firstly, for the 100,000 tonnes of shower gels and liquid soaps – i.e. the quantity assumed to contain microplastics - 15% of the manufacturing companies are taken into account. From the resulting figure of 15,000 tonnes, 10% – 1,500 tonnes – are taken as the amount of products containing microparticles. Of this second interim result , 10% of the mass of these products is taken – giving a figure of 150 tonnes of microplastics."*

Using the BUND list (2014), it can be concluded that microplastics are found not only in the product group 'bath and shower gels', 'liquid soaps', but also in the groups 'cleansers for body care', 'skin-care and sun protection products', 'dental hygiene products' and 'other body-care articles'. No representative data relating to quantities of microplastics used are available for any of these product groups. Therefore, the authors of this report decided to transfer the assumptions 1 to 4 to the other product groups as well.

Extending assumptions 1 to 4 to the product group 'cleansers for body care', a production volume of 118,000 tonnes would mean a further 177 tonnes of microplastics used in Germany each year. For the product group 'dental hygiene products', with production of 65,000 tonnes we have another 98 tonnes of microparticles. The product group 'other body-care articles', with production volumes put at 21,000 tonnes per year (Table 2), adds a further 32 tonnes to the quantity of microplastics used in Germany.

To determine the content of microplastics in the product group 'skin-care and sun protection products' two published sources can be used in addition to the above approach. Firstly, M. R. Gregory (1996) identified the percentage of polyethylene microparticles in three facial cleansers and three hand washes on the New Zealand market. The facial cleansers contained between 1.62 and 3.04% microparticles, the hand washes between 0.19 and 6.91%, in relation to the total weight of the respective products. In 2013, five US environmental associations analysed the microplastic content of three facial cleansers. The percentage of microparticles in these cleansers, based on volume, ranged from 0.94% to 4.2% (5 Gyres Institute et al. 2013). The arithmetic average of the total of six samples of facial cleansers used in the two sources is 2.4%. Assuming that cosmetic products in the group 'skin-care and sun protection products' contain an average of 2.4% rather than 10% microplastics, a production volume of 109,000 tonnes gives a further 39 tonnes of microplastics used in Germany each year.

The following table gives an overview of the extent of microplastics use in cosmetic articles for the different product groups in Germany.

Table 3 Overview of quantities of microplastics used in cosmetics (Source: Authors' own table)

Product group	Quantity of microplastics used per product group in Germany (tonnes per year)	Per capita consumption of microplastics per product group in Germany (grams per year)
Shower gels and liquid soaps	150	1.9
Cleansers for body care	177	2.2
Skin-care and sun protection products	39	0.5
Dental hygiene products	98	1.2
Other body-care articles	32	0.4
Total	496	6.2

According to these preliminary estimates, a total of around 500 tonnes of polyethylene microparticles are used in Germany each year in the five product groups 'shower gels and liquid soaps', 'cleansers for body-care', 'skin-care and sun protection products', 'dental hygiene products' and 'other body-care articles'. With a population of 80 million, this corresponds to 6.2 grams per capita and year. Applying this per capita value to the 500 million residents of the EU gives a total volume of 3,125 tonnes of polyethylene microparticles which are used in cosmetic products in Europe in one year.

3.2 Use of primary microplastics in other areas of application

Primary microplastics also have other applications: as abrasive beads in detergents and maintenance products or as blasting abrasives in surface cleaning. Microplastics are also used as lubricants or abherents in plastics processing, as a carrier for pigments or as an additive to control the viscosity of hot glues. They are also used in coating materials for glossy magazines or to protect fruit from bruising. Water softeners may also contain microplastics. Some microparticles are used as vectors for active pharmaceutical ingredients. The following sections describe these and other examples of the uses of microplastics.

3.2.1 Detergents, cleaning and maintenance products for floors in private households

In 2013 around 120 member companies of the detergent and cosmetics industry association Industrieverband Körperpflege- und Waschmittel e.V. (IKW) manufactured detergents, cleaning and maintenance products. These products were sold to end users primarily in Germany for over 4.3 billion euros. According to the IKW, its member companies do not use microplastics in these products (Rettinger 2014). At the beginning of 2014 Henkel stated that its detergent and cleaning product formulae containing abrasive particles only use natural minerals. However, it cannot be ruled out that other manufacturers of detergents, cleaning and maintenance products use plastic abrasives which enter the environment after use in the form of microplastics. There is currently no robust data on the quantities of microplastics used in detergents, cleaning and maintenance products for floors in private households.

3.2.2 Detergents, cleaning and maintenance products in trade and industry

According to the industry association Hygiene und Oberflächenschutz (IHO), which represents companies manufacturing cleaning agents and disinfectants for commercial purposes, its member companies do not use microplastics in their products. Microparticles in liquid and powder abrasive cleansers can consist of calcium carbonate, aluminium silicate, clays or other anorganic materials. Some water-based floor care agents do contain particles of polyethylene waxes, but these are not microplastics according to the IHO (Faubel 2014). Scientific studies refute this statement. Leslie (2014) describes polyethylene waxes as non-degradable and water-insoluble solid materials, with melting points well above maximum sea temperatures, and therefore classifies them as microplastics.

The authors' own research found that IHO member companies use emulsions which contain microparticles of polyethylene waxes. Manufacturers of care and maintenance products use around 10 tonnes of such emulsions in floor maintenance products. When these products are applied to floors, the particles set in a polyacrylate matrix as the product dries. Subsequent cleaning removes these particles again, embedded in larger matrix sections. It has not yet been established whether wastewater treatment plants can filter these particles out of the wastewater once they enter the sewage system (Section 4.3).

3.2.3 Blasting abrasives for deburring surfaces

The authors' own research shows that at least one company in Germany markets microplastics as blasting abrasives – the firm Arteka in Backnang-Waldrems, Baden-Württemberg. It sells blasting abrasives composed of polyamide 6, polycarbonate and of a thermoset made of urea formaldehyde resin. Particle size is between 100 micrometres and 2.5 millimetres. All particles have a relative density greater than 1. According to company information, in 2010 and 2013 around 15 tonnes of these blasting abrasives were sold. In 2013 around 70% of the quantity sold was made of polyamide, 6.25% of thermosets and 5% of polycarbonate. The company states that polyamide 6 particles in compressed air or wheelblast systems are used to deburr surfaces made of aluminium, zinc die-cast or thermoset components. Thermoset particles are used to clean injection moulding and extruder screws, to deburr plastic and light metal parts and remove paint from delicate workpieces such as powder-coated parts, aircraft components, aluminium wheel rims and pleasure craft. Polycarbonate particles are intended for deburring plastic and light metal parts. Research for this study could not conclusively establish the total volume of microplastics used as blasting abrasives. However, at least the use of blasting abrasives for cleaning ship hulls in dockyards is a major input source, since they are used in an open environment and the microplastics enter open water bodies directly after use.

3.2.4 Applications in medicine

Microplastics are used in the medical sector as well. Hollow particles, for instance, are used as vectors for active pharmaceutical ingredients. The active substances are placed in the hollow interior and slowly diffuse through the body. Microplastics are also being considered to treat reflux – the backflow of gastric acids into the oesophagus due to weak sphincter muscles. Today, the sodium hydrogen carbonate treatment commonly used since the 70s has been replaced with preparations containing aluminium hydroxide and magnesium hydroxide gels, or mixtures of calcium and magnesium carbonate or aluminium magnesium silicate hydrate. Hydroxides, carbonates and silicate hydrates help to buffer the gastric acids, thus alleviating their acidic effects. Products containing aluminium, including such medicines, have come under criticism recently due to the possible toxicological impacts of aluminium compounds (Federal Institute for Risk Assessment, BfR, 2014). It is therefore possible that microplastics may be used more often in future. Unfortunately, neither the quantities of microplastics used in pharmaceuticals nor the possible entry pathways into the environment have been studied in any detail up to now.

3.2.5 Micronised synthetic waxes in technical applications

Microplastics can also consist of micronised synthetic waxes. These are homopolymeric waxes of fine powder with particle sizes in the micrometre or lower millimetre range. It is important to note that in some applications microparticles of synthetic waxes can lose their micro character by being bound in a matrix.

Synthetic waxes differ from 'real' plastics in the molar mass of the polymers used. According to Ullmann’s Encyclopaedia of Industrial Chemistry, polymers in waxes have a molar mass of 2,000 to 20,000 g/mol, while that of polymers in actual plastics is greater than 100,000 g/mol.

In spite of these differences, scientific studies identify synthetic waxes as a source of microplastics (Leslie 2014). Table 4 gives an overview of the main applications of micronised synthetic waxes as additives and auxiliary agents for technical processes.

Table 4 Main applications of micronised synthetic waxes in technical processes (Source: Authors' own table)

Applications of synthetic waxes	Function
Pigments/masterbatch	binding materials and carriers for pigment concentrates for dyeing and additive finishing of plastics
Plastics processing	lubricant or abherent for moulding plastics such as PVC
Adhesion promoters, hotmelts	additive for controlling viscosity
care	▪ additive for wear-resisting films in floor care ▪ protection against water marks and dirt in vehicle care ▪ protection of surfaces in leather and furniture maintenance
Inks	additive to enhance rubbing fastness
Paints	additive to protect surfaces or to create matting effects
Food coating	additive to protect fruits

Synthetic waxes added, for instance, to the polymer polyvinylchloride as a lubricant in technical processes prevent the polymer from sticking to the hot surface of the machine during processing. In care products for shoes, furniture, car paint and floors they enhance shine or improve safety through better slip resistance. Finely dispersed in water they give textiles a smoother surface, making them easier to sew and protecting them longer against linting. Coating the paper of glossy magazines with wax prevents the ink from sticking to the reader's hands. A thin layer of polyethylene wax on the peel of citrus fruits protects them from drying out or bruising.

The chemical company BASF, based in Ludwigshafen, produces polyethylene waxes and markets them under the trade name Luwax and Poligen. These are waxes and wax emulsions which BASF (2007) says are used to aid technical processes or as additives for modifying product properties. Polyethylene waxes are available as powder, pellets or pastilles. Size can vary by up to 7 millimetres. BASF's total production capacity for PE waxes is up to 45,000 tonnes per year. The production plants are in Ludwigshafen. According to a company statement, BASF has studied the toxicological properties and the biological behaviour of PE waxes in the environment and has found no harmful effects. However, the authors could find no results or publications relating to such a study at the time of compiling this report.

Micronised synthetic waxes are produced by other companies as well. The Swiss company Clarian markets such waxes under the trade names Licowax, Ceridust, Licolub, Licomont and Licocene. They are available as fine granules with an average particle size of less than 2 millimetres, as a powder with a particle size of less than 500 micrometres, as a fine powder with a particle size of less than 125 micrometres, and as a micropowder comprised of particles less than 50 micrometres in size. However, the company does not publish any information on production quantities or capacities.

The German concern Evonik Industries AG has an annual production capacity of over 400,000 tonnes of technical polymers and high-performance polymers. The company states that less than 10% of its technical polymers and high-performance polymers are sold each year as particles significantly smaller than 5 millimetres, as powders or in fine dispersions. According to company figures, this would be less than 40,000 tonnes. However, the particles are processed in such a way that they lose their micro form. The vast majority of these microparticles consist of the polymers polyamide 12 or methacrylate copolymers, especially PMMA. Most of these particles are used in metallisation (e.g. for wire baskets in dishwashers), as additives to improve the properties of paints and in the manufacture of fibre composites, for instance in the automotive and sports industries. Special PMMA moulding compounds and high-performance polymers such as polyether ether ketone (PEEK) are used in medical products, for instance spinal implants, bone cement, cannulas and catheters.

Based on their research, the authors of this study assume that up to 100,000 tonnes of micronised synthetic waxes are used in Germany. How much of this is introduced into the environment ultimately depends on the application. The huge number of applications and the lack of data on total production volumes or percentage breakdown of the different applications make it impossible to give any more detailed information on the quantity or fate of microplastics from micronised synthetic waxes discharged into the environment.

3.3 Sources of secondary microplastics

Besides primary microplastics, which are manufactured directly in microscopic sizes for use in cosmetics and other products, secondary microparticles can arise from the fragmentation of macroscopic plastic debris. Secondary microplastics can come from plastic packaging disposed of in the environment, such as plastic bags and bottles, be washed out of man-made fibres in textiles or be generated by tyre abrasion. Such particles also arise during the manufacture or recycling of plastics. Ryan et al. (2010) also describe direct inputs from ship waste. The following sections present further sources of microplastics.

3.3.1 Fragmentation of plastic debris

Production of plastics has been rising since the 1950s. In 2012 chemical companies manufactured approximately 290 million tonnes of polymerised raw materials worldwide, in the form of plastic granules or pellets (PlasticsEurope 2013). Plastics processing companies use these to make plates, pipes, films and other pre-products which are then used by manufacturers of finished products in various industries (packaging, construction, electronics etc.). Some plastics are reused, others are recovered for materials or energy while others are deposited in landfills. However, a substantial portion enters the environment where it is broken down over time into smaller pieces by the sun, wind, tides and other environmental influences, ultimately turning into microplastics.

In 2012, around 57 million tonnes of plastics were produced in the EU. This was around 20.4% of global plastics production (PlasticsEurope 2013). In the EU itself, companies reprocessed just under 46 million tonnes of plastics in 2012 – around 27.5 million tonnes into durable products and more than 18 million tonnes into short-life products. In the same year, around 25.2 million tonnes of plastics were collected after use. Of these, according to PlasticsEurope figures, 6.6. million tonnes (26.3%) underwent mechanical or material recycling, 8.9 million tonnes (35.6%) were recovered for energy and 9.6 million tonnes (38.1%) were landfilled (Figure 2).

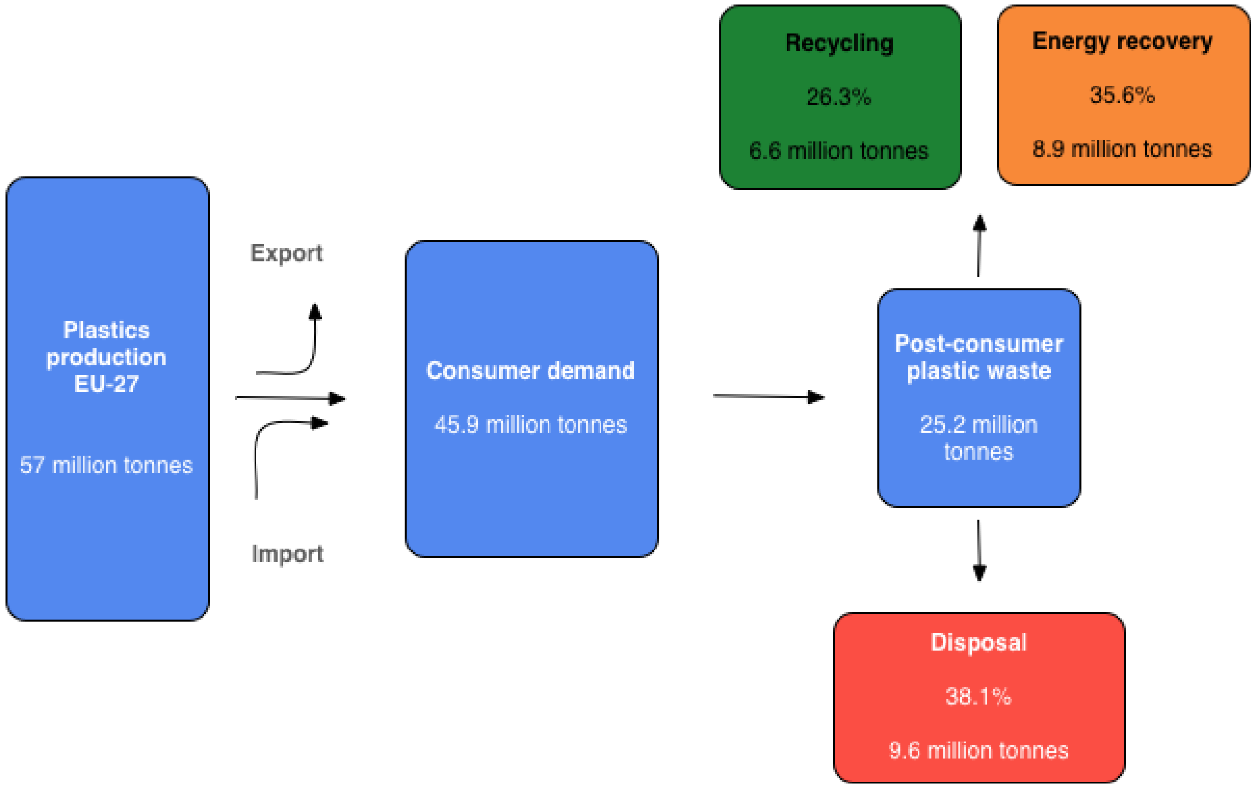

Figure 2 Plastics production, consumer demand, quantities and treatment of waste in Europe in 2012 (Source: Adapted from PlasticsEurope 2013)

The Federal Republic of Germany's foreign trade and investment agency, Germany Trade and Invest states that Germany is the main location for plastics production in Europe (Görlitz & MacDougall 2013). Production volumes, the number of manufacturing and processing operations and the figures for turnover and trade support this. Around 20.7 million tonnes of plastics were produced in Germany in 2011. A further 8.4 million tonnes of plastic were imported and 11.9 million tonnes exported as raw materials (Consultic 2012). The net amount of total plastics consumption in 2011 thus stood at 17.2 million tonnes. For the same year, Consultic (2012) puts plastics consumption of private and commercial end users at 9,65 million tonnes. Of the 5.45 million tonnes of plastic waste arising in Germany in 2011, 3.03 million tonnes were recovered for energy and 2.35 million tonnes for materials (Consultic 2012). The 2011 recovery rate for plastic waste in Germany thus stood at 99% of total volume, with just 1% or 0.07 tonnes being landfilled.

However, recovery and landfill rates vary widely from country to country in Europe. For instance, in 2010 recovery rates for municipal waste was over 90% in Germany, Belgium and Sweden, in contrast to a 90% landfill rate in Bulgaria, Rumania and Malta (Eurostat 2010).

Over the life-cycle of different products, from manufacture and use to waste management, there are numerous ways for plastic waste to enter the environment and in particular the world's oceans. While no definite data can be given on either the main input paths or current quantities some estimates have been made:

- UNEP estimates that in the 1990s around 6.4 million tonnes of plastic litter were introduced into the world's oceans. Nearly 5.6 million tonnes of this came from merchant shipping (UNEP 2006). This is around 6% of global plastics production which in 1990 stood at over 100 million tonnes.
- Wright et al. 2013 make the assumption that around 10% of plastics produced worldwide are discharged into the oceans at some point. This would mean that, of the more than 100 million tonnes of plastic produced worldwide in 1990, about 10 million tonnes will enter the oceans sooner or later. Of the 288 million tonnes produced worldwide in 2012, 30 million tonnes will end up in the oceans. Assuming a world population of around 7 billion people in 2013, this would be equivalent to around 4.2 kg per capita each year.

Assuming that approximately 6 to10% of plastics find their way into the world's oceans, in a European context and based on a constant production volume of 57 million tonnes per year, this would mean between 3.4 million and 5.7 million tonnes of plastics are a source of microparticles. The following chart presents this relationship at global level for the period 1950 to 2012.

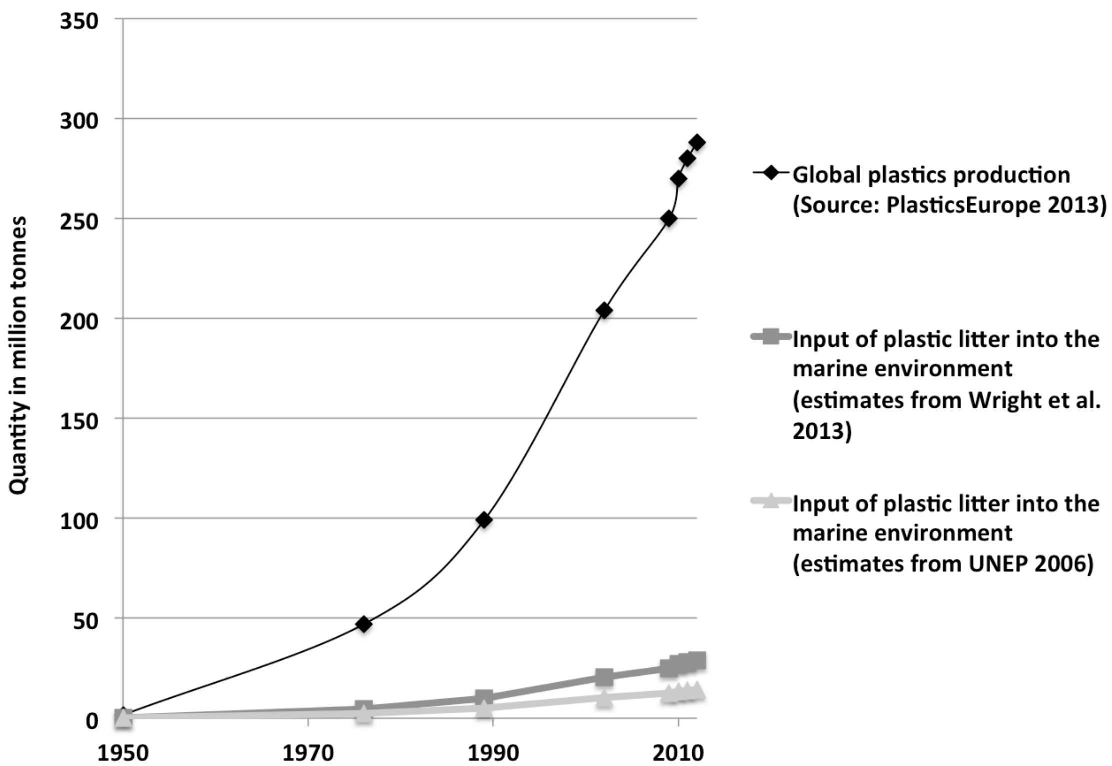

Figure 3 Global production of plastics in the period 1950 to 2012 and estimated input of plastic litter into the marine environment (Source: Authors' own chart based on Plastics Europe 2013, UNEP 2006, Wright et al. 2013)

3.3.2 Discharge of synthetic fibres from textiles

Fibres from clothing and other textiles are also a possible source of microparticles in water bodies. Man-made fibres from synthetic polymers are particularly relevant in the context of this study. They are produced from crude oil through polymerisation, polycondensation or polyaddition processes. Examples of man-made fibres from synthetic polymers include polyester, polyethylene and elastane (figure 4). They are used to make household textiles (e.g. curtains, carpets, terry cloth products), clothing fabrics (e.g. pullovers, t-shirts, socks) and technical textiles for the automotive industry, health sector or structural engineering.

Total production of synthetic fibres climbed from around 2.1 million tonnes in 1950 to around 49.6 million tonnes in 2010 (IVC 2012). IVC (2012) puts the market share of synthetic fibres in 2010 at 59%, followed by cotton (33%), cellulosic synthetic fibres (6%) and wool (2%).

There is very little reliable literature on the discharge of synthetic polymer fibres into the world's oceans. Studies of bed linen, fleece jackets and shirts made of synthetic fibres which were washed at 40°C at 600 revolutions per minute found more than 100 fibres per litre of wastewater (Browne et al. 2011). On average, around 260 fibres were shed from a fleece jacket, around 150 from a shirt, 130 from a bed sheet. The maximum amount the study found was 2,900 fibres from a fleece jacket (Browne et al. 2011). Textiles can also lose fibres during their phase as a result of mechanical abrasion or other processes.

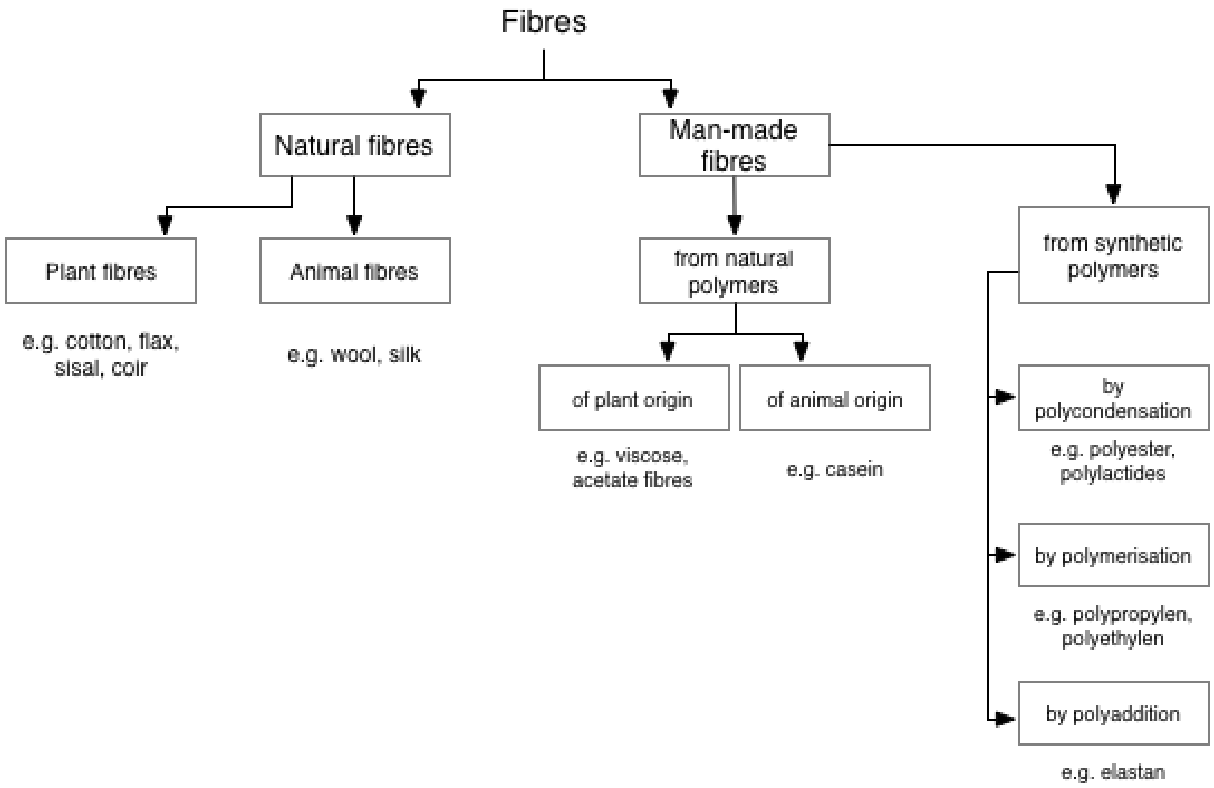

Figure 4 Fibre types categorised according to raw material and production process (Source: Authors' own chart based on IVC 2012)

The significance of synthetic fibres as a source of microplastics becomes apparent from the following assessment by the authors of this study. Making the assumption that each of the 500 million people in Europe owns at least one fleece pullover with an average weight of 500 g and that over 5 years of use the weight of the pullover falls by 1% to 5% due to microparticle loss during laundry cycles, the total quantity of microplastics from this source is 500 to 2,500 tonnes per year. Applying this calculation to Germany's population of 80 million, this would mean 80 to 400 tonnes of microplastics are discharged into the environment each year.

To date there are no reliable figures for how many fibres an average household discharges in this way. In response to a direct enquiry Browne (2014) gave the opinion that such research would require extensive funding, which so far neither government nor industry in Europe or the USA are willing to provide.

3.3.3 Loss of pellets in the manufacture and processing of plastic

DIN EN ISO 472 defines the term pellet as a “small mass of preformed moulding material, having relatively uniform dimensions in a given lot”. Pellets are often used in the manufacture and processing of plastics, for instance as feedstock in moulding and extrusion operations (DIN 2013). These processes can lead to waste and loss of pellets. Manufacturers throughout the world are seeking to minimise the loss of plastic pellets during manufacture, processing, transport and recycling. The plastics department of the American Chemistry Council (ACC) and the US-based Society of the Plastics Industry (SPI) launched the joint initiative 'Operation Clean Sweep', aimed at minimising plastic waste, thus saving money and reducing the amount of plastic litter in the environment. In Europe, the European association of plastics manufacturers, PlasticsEurope has developed its own clean sweep programme for member companies with a 'zero pellet loss' objective. The project aims to raise awareness within the chemical industry and optimise operations.

To date, however, no figures have been published on the success of the zero pellet loss and clean sweep projects, either at European level or internationally. A recent progress report, for instance, listed commitments and projects at international level, but gave no quantities of microplastics that had been prevented from entering the environment because of these projects (GPA 2014). On top of this, individual companies provide no data on production volumes or pellet loss, citing corporate secrecy. For this reason, no clear statement can be made on how many pellets enter the environment directly from plastics production or from downstream processing stages.

A study by the German plastics industry platform on plastics and recycling, *Beteiligungs- und Kunststoffverwertungsgesellschaft* (BKV), however, notes that resource efficiency in the manufacture of plastics has grown significantly over the past 50 years. The study finds that in 1964 plastics manufacturers needed on average 1,185 kg of raw and auxiliary materials to produce 1,000 kg of polypropylene. By 1999, this had fallen to 1,009 kg of raw and auxiliary materials (BKV 2010). Current figures for polypropylene indicate a yield of over 99.7% (Sartorius 2012).

To quantify this source for secondary microplastics, the authors of this study have made the assumption that pellet loss in Europe is in the lower percent region of total European plastics production. Assuming pellet loss in Europe only amounts to around 0.1 to 1.0 percent of total European plastics production of 57 million tonnes, this source accounts for between 57,000 and 570,000 tonnes microparticles per year. For the plastics industry in Germany, producing around 21 million tonnes of plastics (Section 3.1), this would mean between 21,000 and 210,000 tonnes of microplastics per year.

3.3.4 Abrasion of synthetic rubber tyres

Synthetic rubber differs from typical plastics. It is a synthetic polymer which is turned into an elastomer through the linking of polymer chains by sulphur bridges. Most of the rubber elastomers used are a mixture of natural and synthetic rubber. Around two thirds of synthetic rubber manufactured is made into tyres. During their life, tyres can lose small particles due to abrasion and these particles can be classified as microplastics under the definition used in this study (Chapter 1).

In 2005 annual tyre abrasion nationwide stood at approximately 111,000 tonnes, plus around 12,000 tonnes abraded from brake pads. These figures are based on studies by the Fraunhofer Institute for Systems and Innovation Research (ISI) (Hillenbrand et al 2005; Fuchs et al. 2010). The experts conclude that tyre abrasion from passenger vehicles accounts for around 46,000 tonnes per year, while abrasion from buses, trucks and articulated lorries causes around 62,570 tonnes.

In contrast, the organisation of German manufacturers of tyres and technical elastomer products, *Wirtschaftsverband der Deutschen Kautschukindustrie* (WDK), puts the figure for 2005 at just 60,000 tonnes of microplastics from tyre abrasion. This difference is due to the WDK assumption that only 17,000 tonnes of tyre material is lost to abrasion annually from tyres, trucks and articulated lorries.

In total, between 60,000 and 111,000 tonnes of microplastics can thus arise due to tyre abrasion in Germany each year. At a population of 80 million, this corresponds to a per capita figure of 0.75 to 1.38 kg per year. Applied to the 500 million citizens of the EU, tyre abrasion as a source of microplastics accounts for a total quantity of between 375,000 and 693,750 tonnes of microparticles. As yet, there is no reliable information on the fate of microplastics from tyre abrasion in the environment, in particular in the world's oceans, but they are, for instance, among the main finds in the Baltic Sea (Noren and Magnuson 2010).

4 Discussion

There are many sources for primary microplastics (Chapter 3) but as yet there is no robust data on the quantities of primary microparticles used in cosmetic products and other applications which enter the environment, in particular the marine environment, after use. Data on the amount of secondary microparticles originating from the degradation of plastic debris in marine ecosystems are equally sparse. This study carried out research and calculations to close this gap. The results are discussed in the following section.

4.1 Sources of primary microplastics

Cosmetic products are one of the main sources of primary microplastics. The quantities of microplastics used in Germany and Europe for the manufacture of cosmetic articles can be estimated using a number of methods. As shown in Section 3.1, a study by Gouin et al. (2011) uses market data to determine approximate figures for the number of polyethylene microparticles used in shower gels and liquid soaps on the US market in 2009. This approach can be transferred to Germany. If we assume that the daily per capita consumption calculated by Gouin et al. (2011) of 2.4 mg PE microparticles in liquid soaps and shower gels also applies to Germany, a population of 81.8 million people would mean that in Germany a total of 71.5 tonnes of polyethylene microparticles in liquid soaps and shower gels are used each year.

This assumption has the disadvantage that it is based on the population figure and therefore depends on the personal care preferences of the average citizen in the US or Germany. Germans, for instance, use on average twice as much liquid soap and shower gel as Americans: According to Gouin et al. (2011) 195 million litres of shower gel and liquid soap are produced in the United States. With a population of 300 million and based on a concentration of $1 g/cm^3$ this corresponds to an annual per capita consumption of 0.65 kilograms of liquid soaps and shower gels. In Germany, on the other hand, around 100,000 tonnes of shower gels and liquid soaps are produced and used (Section 3.1). With a population of around 80 million, this corresponds to a per capita consumption of 1.25 kilograms per year. Imports and exports can be ignored here, since shower gels and liquid soaps are generally used where they are produced because their transport is not economically viable (Rettinger 2014).

The authors of this report therefore opted for an approach which is not based on population size and thus does not depend on differing personal care preferences or consumption habits. The authors found that each year in Germany up to 500 tonnes of microplastics composed of polyethylene are used in soaps, liquid soaps, shower gels, syndets, skin-care and sun protection products, toothpastes and other body-care products. This is equivalent to an annual per capita consumption in Germany of 6.2. grams. Applied to the 500 million residents of the EU this would mean a total quantity of 3,125 tonnes of microplastics that are used in cosmetic products each year.

The assumptions made in Section 3.1 to calculate the quantities of microplastics used in cosmetic products significantly influence the results of this study:

- In the first place, the approach of applying the production statistics of the manufacturers of cosmetic products in the US to the German market has its defects. It is questionable whether it is also the case in Germany that 15% of companies use microplastics in 10% of their products. Unfortunately, there is no market information which can be used to correct this potential for error. In view of corporate secrecy and the lack of willingness to provide information, it is also doubtful whether even an elaborate market analysis would be able to gather this information.
- Furthermore, the amount of microplastics used in different cosmetic products in Germany and Europe is not known. Taking the US figure of 10% risks under- or overestimating the quantity used – both within one product group and across the different groups. With the exception of 'skin-care and sun protection products', however, it was not possible to obtain any reliable information on the percentage of microplastics used. Screening the ingredients of representative products from each product group would be useful in this context, although a representative monitoring would be complex and costly due to the large number of products in each group and changes in product range and ingredients.
- Moreover, statements on the current quantities of microplastics used in cosmetics is based on the 2002 production figures for this sector. According to the IKW, this quantity has remained relatively constant up to the present, but the only reliable data currently available for body-care products is the article by Tolls et al. (2009). Neither manufacturers nor the IKW provide information on annual production volumes in Germany. The only regularly published data relate to the value in euros of the different groups of cosmetic products manufactured in Germany. However, estimating production volume using the production value is liable to further error due to the price and production volumes of the different products (smaller production volumes often yield higher revenues than larger ones), price fluctuations on the market and rising efficiency in the production process. Transparent and up-to-date market data would be extremely helpful in facilitating future estimates of the quantities of microplastic inputs into the environment, as this data forms the basis for all calculations.
- In addition, all calculations and assumptions relate to just one type of plastic – polyethylene. Numerous literature sources show that other plastics are used besides polyethylene (BUND 2014; Leslie et al. 2012, Leslie 2014). These are not just used as

abrasives. Some polymers help to finely disperse water-soluble or oil-soluble substances, others play a role in coherent film formation for cosmetic products applied to the skin, hair or nails. There is currently no information on the quantities used or the percentages of the respective plastics and polymers. Nor is anything known of the potential risk posed by the input of these substances into the environment, whether as microplastics or in other form.

- Another factor to be borne in mind is that natural substances are already being used which could replace conventional plastics in cosmetic products. A recent edition of the consumer magazine Öko-Test lists, among other substances, powdered apricot kernels, powdered bamboo, powdered rice and the minerals quartz and silicic acid. (Markert 2014). Their share in the products of the relevant product groups is currently not known, but whether the microparticles are synthetic or natural is highly relevant for determining the precise quantities of microplastics discharged into aquatic ecosystems. This presents the industry with an excellent opportunity to inform consumers about their products' properties and ingredients and, for instance, to highlight that they have opted out of using conventional plastics.
- All calculations relate to the five product groups 'shower gels and liquid soaps', 'cleansers for body care', 'skin-care and sun protection products', 'dental hygiene products' and 'other body-care articles'. Nevertheless, it cannot be ruled out that articles in other product groups of the cosmetics industry may also contain microplastics. A broad screening of all cosmetic product groups could help shed light in this area as well.

All these factors mean that considerable uncertainties remain regarding quantities of microplastics used in cosmetic products. In view of all the potential for error, the figure of 500 tonnes of microparticles should be understood as an approximate range rather than indicating the precise amount. That figure would mean that microparticles in the three-figure tonnes are used in cosmetic products in Germany. To verify the quantity, in future research projects such as broad-based screening and monitoring of the ingredients of representative cosmetic articles from all product groups could be carried out and manufacturers and associations could conduct a market analysis of the manufacture and use of microplastics. The association Cosmetics Europe has already completed such an analysis at European level, but the results were not available when this report was being compiled.

Besides their use in cosmetic products there are many other applications for primary microplastics (Section 3.2). The authors' own research found that in small quantities – i.e. considerably less than 100 tonnes per year – such particles are used in commercial cleaning products and as blasting abrasives. The total quantity of all micronised synthetic waxes produced in Germany is probably in the six-figure range. To date, no figures are available on the quantities of microplastics used in cleaning agents for private households or in medicines. The following table summarises the quantities of microplastics used in cosmetic articles and other applications, as estimated by the authors.

Table 5 Quantities of microplastics used in cosmetic products and other applications (Source: Authors' own table)

Applications of primary microplastics	Quantities of primary microplastics used in Germany in tonnes per year
Cosmetic products	500
Detergents, cleaning and maintenance products in private households	no data available
Detergents, cleaning and maintenance products in trade and industry	< 100
Blasting abrasives for deburring surfaces	< 100
Applications in medicine	no data available
Micronised synthetic waxes in technical applications	100,000

The table shows that the main use of microplastics is in micronised synthetic waxes in technical applications. However, there is also great uncertainty as to which uses of synthetic waxes are the cause of microplastic inputs into the environment (Section 3.2.3).

4.2 Sources of secondary microplastics

Sources of secondary microplastics are fragmentation of plastic debris, synthetic fibres from clothing and other textiles, pellet loss during the production and processing of plastics and tyre abrasion in road traffic (Section 3.3).

Fragmentation of plastic debris is the most significant source of secondary microplastics. While here, too, there is a lack of detailed information on the precise quantity of plastic debris entering the environment across Europe, as well as on the rate at which these give rise to secondary microplastics, rough estimates by the scientific community and the United Nations Environment Programme indicate non-negligible inputs from these sources. According to these estimates each year between 6 and 10% of global plastics production ends up as marine litter. For Europe, this is equivalent to 3.4 to 5.7 million tonnes.

One typical example of plastic waste in the environment which is under frequent discussion is caused by incorrect disposal of single-use carrier bags. Each year EU citizens handle around 100 billion plastic bags. At an average weight of 6g per bag, that is equivalent to around 600,000 tonnes of plastic. This means that every resident of the EU uses an average of 200 bags per year – or 1.2 kilograms of plastic. Around 89% of these plastic bags are used once. The EU Commission estimates that about 8 billion plastic bags enter the environment every year (The Greens/EFA 2014). At 6 g per bag, this represents a total of 48,000 tonnes entering the environment in the EU alone.

In Germany between 60,000 and 111,000 tonnes of microplastics are caused each year by abrasion of car tyres. The figure for Europe is between 375,000 and 693,750 tonnes. Thus, the debate on microplastics cannot ignore car tyre abrasion as a source.

The authors estimate pellet loss during plastics production in Europe at between 57,000 and 570,000 tonnes per year and between 21,000 and 210,000 tonnes in Germany. This is likely to fall in future due to the industry's own interest in making production as efficient as possible. For this field too, however, manufacturers and associations still have not published any reliable figures or literature. This source should therefore continue to be considered in future work on microplastics in the environment.

Synthetic fibres from clothing and other textiles have been the focus of scientific studies for some time. Quantitative data on the size of this source of microplastics is nevertheless lacking. The authors estimate the figure at around 80 to 400 tonnes of microplastics per year in Germany and between 500 and 2,500 tonnes per year in Europe. The table below gives an overview of the extent of the different sources for secondary microplastics.

Table 6 Sources of secondary microplastic in Germany and Europe (Source: Authors' own table)

Sources of secondary microplastic	**Germany***	**Europe***
Fragmentation of plastic debris	unknown	3,400,000 to 5,700,000
Tyre abrasion	60,000 to 111,000	375,000 to 693,750
Pellet loss	21,000 to 210,000	57,000 to 570,000
Shedding of synthetic fibres	80 to 400	500 to 2,500

* all figures in tonnes per year

The table shows that fragmentation of plastic debris is the main source of microplastics in terms of quantity, with tyre abrasion also playing a significant role. There are still substantial uncertainties regarding pellet loss and shedding of synthetic fibres. The actual quantities of these two sources may lie well above the conservative estimates of the authors of this study. There is still a particularly great need for further research in the field of synthetic fibres.

4.3 Comparison of sources of primary and secondary microplastics in Germany

Reliable data for littering in Germany and on the fragmentation of plastic debris is missing but given the global and European estimates and together with the losses of plastic pellets from plastic production, trasnport and processing as well as tyre abrasion from road traffic it can be assumed that secondary microplastics play the major role with regard to the marine littering. However, it must be noted that there is no specific data on input paths, accumulation, fragmentation or degradation of these substances in the environment. Bearing in mind that shedding of synthetic fibres account for several hundred tonnes per year, we can speak of a ticking time bomb, since sooner or later the influence of chemical and physical processes will turn these sources into microplastics as well. The following table compares sources of primary and secondary microplastics in Germany.

Table 7 Sources of primary and secondary microplastics in Germany (Source: Authors' own table)

Sources of microplastics in Germany	**Quantity of sources in tonnes of microplastics per year**
Primary microplastics	
▪ cosmetic products	500
▪ detergents, cleaning and maintenance products for commercial and industrial use	< 100
▪ blasting abrasives for deburring surfaces	< 100
▪ Micronised synthetic waxes in technical applications	100,000
Secondary microparticles	
▪ fragmentation of plastic debris	unknown
▪ synthetic fibres from clothing and other textiles	80 to 400
▪ pellet loss during manufacture and processing of plastics	21,000 to 210,000

▪ tyre abrasion	60,000 to 111,000

Microplastics in cosmetic products are a major contributor to pollution, even if their role is a minor one compared to the environmental pressures caused by plastics as a whole. In the worst case scenario, around 500 tonnes of microparticles composed of polyethylene can enter the world's oceans each year from this source. However, in the case of primary microplastics, which also include inputs from detergents, cleaning and maintenance products and blasting abrasives, the particles are already microscopic in size directly prior to entering the environment.

It is highly probably that a large proportion of microplastics from cosmetic products are to be found in municipal wastewaters. In Germany, over 90% of households are connected to the sewage system. Initial, non-representative studies indicate that wastewater treatment plants capture over 90% of the microplastics found in wastewater (HELCOM 2014). Thus, in countries with adequate infrastructures the quantity of microplastics entering the oceans from cosmetic products can be significantly reduced. Nevertheless, in spite of the high level of retention in some wastewater treatment plants, Mintening et al. (2014) found that between 86 and 8,851 microplastics could be detected per cubic metre of purified water. Levels of between 33 and 9,923 per cubic metre were found for fibres smaller than 500 micrometres. Depending on the size of the treatment plant, Mintening et al. (2014) calculate that from 93 million to 8.2 billion microplastics and synthetic fibres are discharged into the outlet channels of wastewater treatment plants in Germany.

To date, there is no reliable data on the location of microparticles in the environment from commercial and industrial detergents, cleaning and maintenance products, blasting abrasives for deburring surfaces or from micronised synthetic waxes. Applications in an open environment certainly have the potential to cause high levels of pollution, for instance microplastics being discharged directly into the ocean when used in dockyards as blasting abrasives.

4.4 Substitution of microplastics in cosmetic products

Microplastics appear to be replaceable or avoidable in cosmetic products. The public debate about the problems caused by microparticles in water bodies is having an impact, particularly in the US and in EU member states. Some companies have already responded: In December 2012 Unilever announced that it would abandon the use of microplastics in cosmetics[2]. In

[2] http://www.unilever.com/sustainable-living/Respondingtostakeholderconcerns/microplastics/index.aspx

spring 2013 Beiersdorf, Colgate-Palmolive and L’Oréal followed suit, with similar steps in July 2013 by Johnson & Johnson, Procter & Gamble and The Body Shop. At the beginning of 2014, L’Oreal gave further details, announcing that as of 2017 none of its product range would contain microplastics (Süddeutsche Zeitung 2014). Research conducted by this study confirms that many other cosmetics manufacturers have either already abandoned the use of these particles or are seeking substitutes. However, no figures are available on how much the use of microplastics in cosmetic products has fallen or will fall. These are after all voluntary commitments by the companies which have not been verified by independent organisations and which can be unilaterally withdrawn at any time without legal consequences.

At the trade fair for personal care ingredients, In-Cosmetics, in Hamburg in April 2014, a number of chemical companies and traders presented a range of substitute products. The chemical company Evonik offers body scrubs made of 'artificial' sand. For reasons of hygiene this is produced on the basis of a synthetic silicic acid rather than by grinding natural sand. The American company MicroPowders sells particles made of polylactide, a polymer produced from corn starch while Swiss chemicals trader Permcos sells body scrubs from hydrogenated palm or castor oil. Microparticles made of cellulose, a component of wood, are offered by both the Swiss chemicals company Induchem and J. Rettenmaier & Söhne based in Rosenberg, Baden-Württemberg. Armin Ungerer, lead researcher at the latter company, stated that some small to medium-sized cosmetics companies are already substituting polyethylene microparticles with particles made from natural materials. Ungerer indicates that larger cosmetics concerns have now also expressed interest in substitute products (Deutschlandfunk 2014, Ungerer 2014).

Alongside natural products such as apricot kernels and beeswax, bio-based and biodegradable polymers are also being discussed as substitute options. Possible candidates are polyhydroxy-alkanoates (PHA), polylactic acid (PLA) and polybutylene succinate (PBS), which are produced by bacteria, chitosan made from chitin and casein from animal protein. Current studies show that while polylactic acid is probably not the answer, polyhydroxyalkanoates are an option for the future (CalRecycle 2012). However, the greatest challenges lie in the technological feasibility to ensure that the entire biodegradation of polymers is guaranteed in natural environments and, furthermore, in the realisation of production volumes and market shares of these polymers.

'Oxo-biological' degradable plastics are not the solution as they are, in fact, another source of microparticles. While some of their manufacturers maintain that such synthetics largely degrade due to biotic processes or decompose through abiotic processes, most of these claims have not been substantiated scientifically. They also fail to note that, in relation to the product's original weight, up to 80 percent of the components remain in the environment following these processes and may develop toxic effects (Narayan 2009).

The following figure shows the biodegradability of different bio-based polymers in various environments.

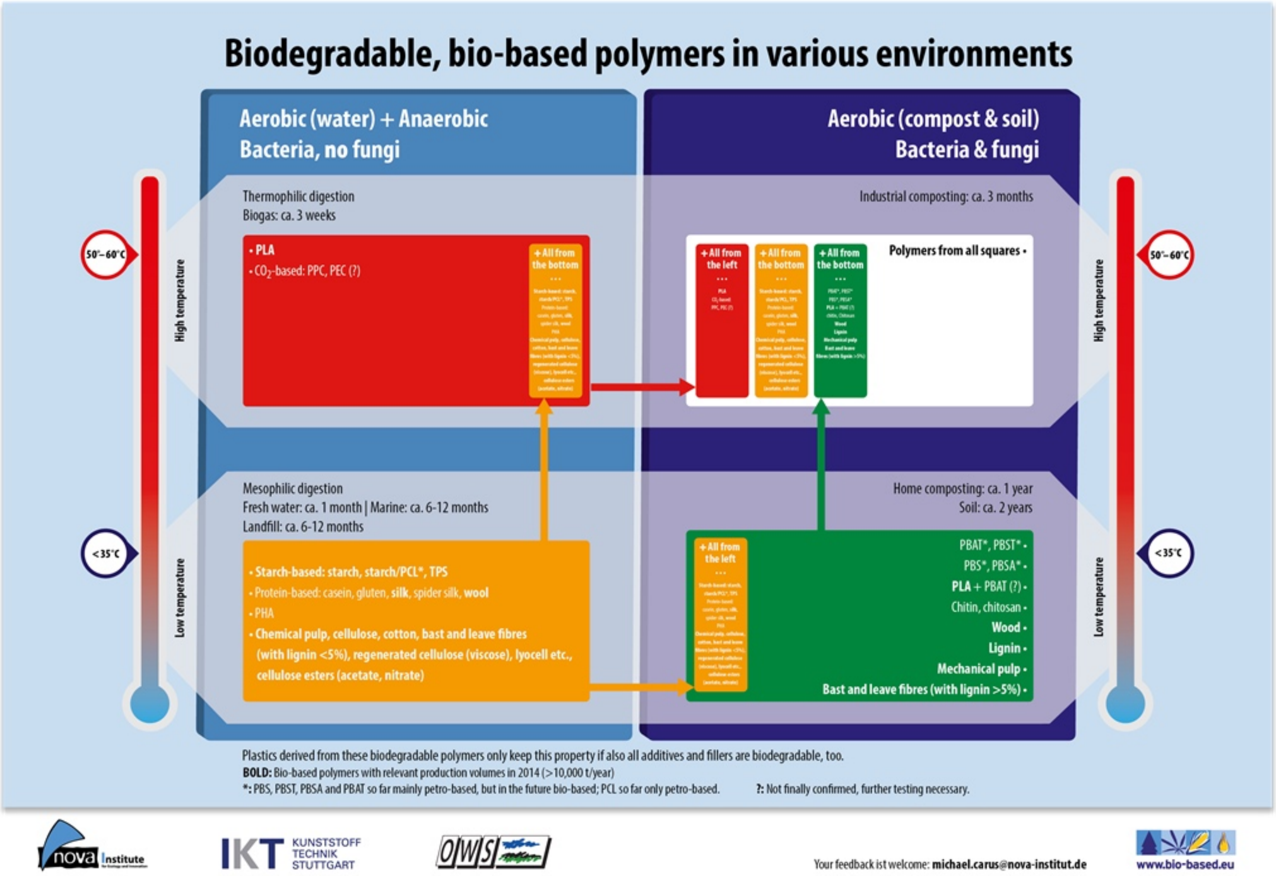

Figure 5 Biodegradable, bio-based polymers in various environments (Source: nova-Institute, IKT & OWS 2015)

5 Conclusion and outlook

Microplastic particles, which are also referred to in the public debate as 'microplastics', are defined in this study as plastic particles with a diameter greater than one micrometre and smaller than five millimetres. The first preliminary estimates undertaken in this study indicate that around 500 tonnes of microplastics composed of polyethylene have been used annually in cosmetic products in Germany in recent years (Section 3.1). The main areas of application are in the product groups 'cleansers for body care' (177 tonnes), 'shower gels and liquid soaps' (150 tonnes) and 'skin-care and sun protection products (39 tonnes). A further 34 tonnes of microplastics are assumed to be used in other cosmetics product groups. Initial preliminary estimates put the total quantity of microplastics used in cosmetic products throughout the European Union at approximately 3,125 tonnes per year.

Microplastics are also used in detergents, cleaning and maintenance products, blasting agents, inks and paints, food coatings, in medicine and a range of technical applications. The authors estimate that less than 100 tonnes per year are used in each of the product groups detergents, cleaning and maintenance agents for commercial and industrial use, and blasting agents for deburring surfaces. For microplastics in synthetic waxes, the authors estimate quantities of around 100,000 tonnes. Unfortunately, there are no precise data available at present for medicine or other applications. It is therefore not possible to give an exact figure for the total quantity of microplastics used.

There is a large knowledge gap regarding what percentage of primary microplastics enter Europe's sewage systems or surface waters, how much is filtered out by wastewater treatment plants or what amount of microplastics ultimately reach the world's oceans. On top of this, microplastics can cause further environmental pollution through the spreading of sewage sludge or through discharge during other applications. There is thus a great need for extensive research with a view to compiling a reliable materials flow analysis, establishing the fate of microparticles in the environment, and determining their ecological impacts.

The quantity of microplastics used in soaps, shower gels and other cosmetic products in Germany is probably declining. Prompted by public criticism, many SMEs as well as larger manufacturers of cosmetic products are now announcing their willingness to abandon the use of these ingredients in future. However, this is not yet the case for other applications, markets or regions. To date, manufacturers of cleaning and maintenance products, detergents and blasting agents or pharmaceuticals have not produced any voluntary commitments in this regard. Therefore, whether the downward trend in the use of microplastics will continue in future cannot yet be confirmed. Voluntary commitments by the industry can be withdrawn at any time, and no global institution to document the environmental problems caused by microplastics and other plastic litter, or coordinate suitable prevention measures is going to be established at any time in the near future.

Other solutions besides ending the use of microplastics are currently being discussed and substitutes for conventional microplastics are being researched. Depending on the application, these include natural products such as beeswax, cellulose, casein and minerals, as well as innovative feedstocks like the bio-based plastics polybutylene succinate (PBS) and polyhydroxyalkanoates (PHA). Nevertheless, there is a huge lack of robust information regarding the natural degradability and potential environmental impacts of both microplastics and their substitutes.

The 500 tonnes of microplastics used annually in cosmetic products are just a fraction of German plastics production, which totals 20.7 million tonnes. Other sources of microplastics are man-made fibres which are washed out of clothing and other textiles, tyre abrasion in road traffic, pellet loss during the manufacture and processing of plastics and the fragmentation of plastic debris in the environment. Taking the worst case scenario, that the total quantity of 500 tonnes of microplastics from cosmetic products are discharged into the sea along the coast of Germany, this would still only represent a small proportion compared to all other sources of microplastic.

Microplastics from cosmetic products thus play only a minor though avoidable role in environmental pollution from plastic. Therefore, to reduce the input of microplastics into the environment, and in particular the marine environment, it is not enough to focus on the use of microplastics in cosmetic products and other applications. Additional measures which drastically cut the overall quantities and the further introduction of plastic litter in the environment are needed – not only in Germany and the EU, but throughout the world.

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