INDICATORS FOR PLASTIC POLLUTION

Scientific Report from DCE – Danish Centre for Environment and Energy No. 553 2023

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Data sheet

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Abstract: Plastic losses to the environment can occur at all stages of plastic production, use and disposal. Once in the environment, plastics occurs in a variety of shapes, size classes and polymers, including dynamics such as accumulation on beaches, breakdown from macro- to microplastics, and uptake in biota. Addressing plastic pollution requires reliable indicators. This study has analysed existing indicators along the plastic value chain and in the environment, including frameworks aiming at circular economy and plastic reuse and recycling. The main part of plastic losses is macroplastic, with an important source being the mismanagement of plastic waste. Thus, this would be a relevant indicator, but it is difficult to measure directly. Environmental indicators exist, which are complementary, but badly connected to upstream indicators in the plastic value chain. Furthermore, important plastic components lost in the value chain and present the environment, respectively, such as tyre abrasion and fishing gear, are not approached consistently. A lack of harmonization, e.g. in reporting units, prevents more consistency in the indicator approach. The report also includes some suggestions of potentially relevant new indicators, such as container losses, ghost nets and microplastics in wastewater.

Keywords: Fisheries, macroplastics, marine environment, microplastics, recycling, waste management

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Commentators on this report were: Norway: Caroline Persson Hager, Norwegian Environmental Agency; Iceland: Katrin Sóley Bjarnadottir, Environment Agency of Iceland; Denmark: Frank Jensen, Ministry of Environment of Denmark; Finland: Julia Talvitie, Finnish Environmental Institute; Sweden: Helén Klint, Åsa Stenmarck, Åsa Andersson, Swedish Environmental Protection Agency. The comments have not influenced the conclusions of the report. The comments are available upon request.

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Preface

This report results from a project initiated by the Nordic Council of Ministers in relation to actions to combat global plastic pollution. In March 2022, the United Nations Environmental Assembly (UNEA) agreed to convene an Intergovernmental Negotiating Committee to develop an international, legally binding agreement to end plastic pollution. This was considered a breakthrough by many stakeholders in this field. However, policy decisions need reliable and robust data to assess the problem as well as the efficiency of regulations. In the complex field of plastic pollution, there is not just one type of measurement. In a global approach, pollution indicators should be applicable worldwide. This is the background for this project.

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The opinions expressed in this report, including discussions and recommendations of specific indicators, are the view of the authors, based on the best of their scientific knowledge.

Sammenfatning

Alle trin fra plastproduktionen, anvendelse og bortskaffelse kan bidrage til tab af plastmaterialet til miljøet. I miljøet forekommer plastpartikler i mange forskellige former, størrelser og polymertyper. De indgår i forskellige processer, der påvirker plastpartiklernes skæbne i miljøet, fra akkumulering på kyster og strande, over nedbrydning fra makro- til mikropartikler, til optagelse i dyr. Undersøgelser af plastforurening kræver pålidelige indikatorer. I dette projekt har vi analyseret eksisterende indikatorer i forbindelse med plastproduktionen, anvendelse og bortskaffelse samt indikatorer i miljøet, hvor vi også har inkluderet strategier for cirkulær økonomi og genanvendelse samt recycling af plast.

Hovedparten af plasttabet til miljøet består af makroplast, hvor utilstrækkelig og uhensigtsmæssig håndtering af plastaffald er en væsentlig årsag til dette tab. Affaldshåndtering kunne derfor være en relevant indikator, som dog er svær at måle direkte. Indirekte fastlæggelser af graden for mangelfuld affaldshåndtering kunne være en mulighed og er beskrevet i rapporten. Flere miljøindikatorer er anvendt i dag, som kan supplere hinanden, f.eks. ved at dække makro- og mikroplast og repræsentere forskellige typer miljøprøver. Selvom der er udviklet guidelines for harmoniserede tilgange, er der fortsat store usikkerheder i bestemmelsesmetoderne, i tillæg til varierende koncentrationer i miljøet. Den store usikkerhed vil påvirke tidsseriernes statistiske styrke, således at signifikante trends vil være svære at påvise.

Der er ikke meget sammenhæng mellem miljøindikatorer og indikatorer fra plastens værdiskabelse. For eksempel er partikler fra slid af bildæk en vigtig komponent i det samlede tab af plastpartikler under anvendelse af produkter, mens det ikke er en vigtig indikator for plast i miljøet. Dette skyldes bl.a. at bildæk med en stor gummikomponent ikke oprindeligt blev betragtet som ”mikroplast”. Derudover har manglen på harmoniserede metoder begrænset undersøgelser af partikler fra bildæk i miljøet. På den anden side er tabt fiskeriudstyr en væsentlig forureningskilde i det marine miljø, som ikke spiller en stor rolle i opgørelser over plasttab under produktion og anvendelse. Der er fortsat begrænsninger i mere sammenhængende opgørelser pga. manglende harmonisering i f.eks. enheder og muligheder for opskalering af eksisterende målinger. Rapporten indeholder også forslag til potentielt relevante nye indikatorer, såsom tab af container fra fragtskib, tabt fiskegarn og mikroplast i spildevand.

Summary

Plastic losses to the environment can occur at all stages of plastic production, use and disposal. Once in the environment, plastics occur in a variety of shapes, sizes and polymers, including dynamics such as accumulation on beaches, breakdown from macro- to microplastics, and uptake in biota. Addressing plastic pollution requires reliable indicators, i.e. measurable parameters that represent plastic pollution or certain aspects of it. This study has analysed existing indicators along the plastic value chain and in the environment, including frameworks aiming at circular economy and plastic reuse and recycling.

The main part of plastic losses is macroplastic, with an important source being the mismanagement of plastic waste, including plastic littering. Thus, the degree of mismanaged plastic waste would be a relevant indicator, but it is difficult to measure directly. Indirect determinations may be possible and have been outlined. Several environmental indicators have been established, which can be used in a complementary way, e.g. covering macro- and microplastics and representing different environmental media. Guidelines have been developed to ensure harmonized approaches. However, uncertainties in determinations remain, in addition to large fluctuations in the environment. For all types of indicators, high uncertainties will affect the power of time series in a way that significant trends will be difficult to detect.

Downstream indicators in the environment are badly connected with upstream indicators in the plastic value chain. An important microplastic component lost in the value chain is tyre abrasion, but this is no typical indicator in the marine environment. Originally, due to the large rubber component in tyre wear, these particles were not considered as microplastics. Furthermore, they may be retained in the terrestrial or freshwater environment and reach the marine environment in smaller quantities. There have also been methodological obstacles and challenges. Lost and abandoned fishing gear is an important pollution type in the marine environment, but scarcely recognized in upstream leakage processes. Consistency is also hampered by a lack of harmonization in reporting units and upscaling practices. The report also includes some suggestions of potentially relevant new indicators, such as container losses, ghost nets and microplastics in wastewater.

1 Introduction

1.1 Background

The production and use of plastics has increased exponentially since the 1950s (OECD, 2022a). The stability of plastic materials, in combination with inadequate waste management and other losses to the environment, has caused a global environmental problem. Today, plastic particles have been found all over the globe, including polar regions and the deep sea (MacLeod et al., 2021). Consequently, plastic pollution is addressed at many geographical scales, from the local to the global level.

The United Nations Environmental Assembly (UNEA) of the United Nations Environment Programme (UNEP) has adopted five resolutions to combat global plastic pollution (Box 1). In March 2022, UNEA endorsed the resolution to end plastic pollution, through a legally binding agreement to be developed until 2024. The resolution addresses the full lifecycle of plastics, including production, use and waste management (UNEP, 2022a).

Attempts to solve the plastic problem need reliable measurements of the type and extent of plastic pollution. Given the variety of plastic materials and uses, indicators have been developed that can represent different parts of the plastic lifecycle. Plastic as an environmental pollutant is particularly complex, covering different polymer types, shapes and size classes that can range from nanoparticles to large items such as fishing gear. Given the number of groups and organizations addressing plastic pollution, various indicators are currently in use.

Box 1: UNEA resolutions on marine litter[1]

UNEA 1: Agreeing on the global emerging threat (2014)
UNEA 2: Identifying knowledge gaps (2016)
UNEA 3: Recognizing the inefficient global governance (2017)
UNEA 4: Strengthening coordination and knowledge (2019)
UNEA 5: End plastic pollution: Towards an international legally binding instrument (2022)

1.2 Objectives

The objectives of this project were as follows:

- Provide an overview of existing indicators for plastic pollution, including existing databases
- Analyse strengths and weaknesses of the indicators and assess what sources of plastic pollution and which ecosystem compartments are covered best by existing indicators
- Identify and analyse gaps of the existing indicators (and those under development) for the leakage of plastics along the value chain, i.e. from plastic production to its disposal as waste, and for the lifespan of plastics
- Provide recommendations for possible indicators at the global scale and further development of existing indicators needed to effectively report and

[1] https://unea.marinelitter.no/

monitor the leakage of plastics to the environment and their presence in the environment. This should also include indicators representing relevant stages of plastic losses in the plastic lifecycle.

- Assess the most cost-efficient and robust indicators, with a view to establish time-series at the global scale
- Provide priority indicators for a global agreement on plastics pollution

2 Approaches

We have approached the topic from a global perspective, with a focus on the global agreement on plastic pollution, while also including regional and local indicators for both macro- and microplastics. The work has included sea-based and land-based sources of plastic and considered indicators from the plastic value chain, i.e. close to sources, as well as environmental indicators, with a focus on the marine environment. Specifically, we have worked with the references listed in Annex 5.1.

In order to structure and categorize the multitude of indicators, we have applied the conceptual Drivers-Pressures-State-Impact-Response (DPSIR) framework, which was developed for the European Environment Agency (EEA, 1999) and has also been employed by e.g. UNEP and the Organization for Economic Co-operation and Development (OECD) (**Figure 1**).

Figure 1: Drivers-Pressures-State-Impact-Response (DPSIR) framework used to structure and categorize the different indicators.

The report suggests a harmonized way of setting up the indicators using the DPSIR concept, including drivers for production and use, pressures covering waste and leakage, state of and impacts on the environment. Response indicators refer to indicators for initiatives for combatting plastic in the environment and the development of solutions. Any combined framework for the description of indicators is challenged by the heterogeneity of the currently collected data. This includes selection of units, temporal and spatial scales and quantification methodologies, and also how different organizations allocate the indicators in the DPSIR scheme. Indicators must provide metrics that are comparable across countries and are consistent over time (UNEP, 2022b).

A purpose of this report is to flag these differences and suggest a way to present the indicators in a harmonized way.

The following chapters correspond to the general outline of the project, i.e.

- Environmental indicators (approached from a wide angle, according to the DPSIR scheme).
- Indicators for leakages along the value chain and the lifespan of plastics (specifying this part of the general overview of indicators), i.e. covering plastic production, use and waste disposal.
- Gap analysis, recommendations and outlook.

3 Results and discussion

3.1 Existing indicators

3.1.1 General remarks

This section will provide an overview of currently applied indicators in different international frameworks and indicators under development. Section 3.2 will describe in detail the indicators for leakages along the plastic value chain, from production and use to plastic waste. For an indicator to be applicable in a scientific and regulatory context it must be quantifiable. Therefore, this document also includes a summary of existing databases that are available and in use as data repositories for indicator data.

3.1.2 The indicator landscape

A number of stakeholders address plastic pollution and associated indicators in various frameworks and directives, approaching the issue from different angles. Combining these activities shows that some, but not all, components of the DPSIR are well represented. Most of them indicate the state and impact indicators for the marine environment. This uneven distribution of indicators does not necessarily mean that indicators are missing and should be developed, as the relevance and need of developing and using indicators may not be equal for the different parts of the DPSIR scheme. A summary of the existing indicators is given in **Table 1**. It summarizes the detailed catalogue of indicators that is given in Annex 5.2 and Annex 5.3. Considering the typical plastic value chain consisting of production, use and waste disposal, production and use would be Drivers in the DPSIR concept, while waste would be a Pressure.

Table 1: Approximate number of indicators in brackets, for each framework. Numbers for Regional Sea Conventions and Action Plans (RSCAP) state the number of frameworks that use the environmental indicators. OECD: Organization of Economic Cooperation and Development. EU: European Union. SDG: Sustainability Development Goal. Directive 2008/98/EC states the use of necessary indicators (not specified) to fulfill the requirements in the directive.

Drivers	Pressures	State	Impacts	Responses
Socio-economic context and characteristics of growth (OECD, Green Growth indicators: 14) Environmental and resource productivity of the economy (OECD, Green Growth indicators: 12) Socio-Economic indicators (OECD: 8) Circular Economy indicators (OECD: 8, EU: 15)	Environmental indicators (OECD: 13) Emissions to environment (SDG: 1) Waste management (SDG: 1) Raw material extraction) (SDG: 1)	Environmental indicators (RSCAP: biota (6), beach litter (10), seafloor litter (5), micro-plastic (5), water column and/or floating litter (3)) Natural asset base (OECD, Green Growth indicators: 10) Marine and coastal environment (SDG: 1) Waste generation and management (SDG: 2)	Impacts on biota (RSCAP: 6) Environmental dimension of quality of life (OECD, Green Growth indicators: 4) Ecosystem health (SDG: 2)	Proof of action implementation (RSCAP: 10) Economic opportunities and policy responses (OECD, Green Growth indicators: 19) Tracking progress (New Plastic Economy Global Commitment: 5) Policy and law (SDG: 1) Waste prevention measures and management (Directive 2008/98/EC, use of indicators: 3)

UNEP (2022b) provides an approach to the development of headline-, core- and sub-indicators, based on existing frameworks. The suggested indicators listed in detail in section III in UNEP (2022b) incorporate goals, targets and indicators developed under the Sustainable Development Goals (SDG), the Framework for the Development of Environment Statistics (FDES), the System of Environmental Economic Accounting (SEEA), Green Growth Indicators and other OECD initiatives, the Strategic Approach to International Chemicals Management (SAICM), and the Basel Convention. The approach to developing the recommended indicators is based on three phases of 1) consolidation, 2) geographic expansion, and 3) improved monitoring of effectiveness of broader holistic and integrated policy measures (UNEP, 2022b).

The OECD has developed several frameworks and initiatives that include indicators related to a sustainable use of plastics. These include the framework of Green Growth and Sustainable Development and the Global Plastics Outlook (OECD, 2022a; 2022b). Indicators are grouped according to: 1) Environmental and resource productivity of the economy, 2) Natural asset base, 3) Environmental dimension of quality of life, 4) Economic opportunities and policy responses. A fifth group of indicators is recommended to describe the socio-economic context and characteristics of growth. Main and proxy indicators which can be considered for plastic data are shown in detail in Annex 5.3.

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel, 2019) controls the transboundary movement of plastic waste. In 2019, the Conference of the Parties to the Basel Convention adopted the amendments BC 14/12 with additional provisions to improve transparency and regulations in the global trade in plastic waste and BC 14/13 on actions to prevent and minimize the generation of plastic waste and to improve its environmentally sound management. The framework supports the SDG indicator on waste generation and management: 12.4.2 a) Hazardous waste generated per capita; and b) Proportion of hazardous waste treated, by type of treatment. Annex 5.2 includes related obligations.

Following decision BC 14/13 of the Conference of the Parties to the Basel Convention, a Small Intersessional Working Group (SIWG) was established to update the technical guidelines for the identification and environmentally sound management of plastic wastes and for their disposal, which had originally been established in 2002. Updated draft versions are currently available (Basel, 2022).

UNEP's Regional Seas Programme consists of 21 Regional Seas Conventions Action Plans (RSCAPs) (UNEP, 2022b). Of these, 14 have developed indicators, including indicators for biota, beaches, seafloors, microplastics, water and proof of action implementation. These are predominantly impact indicators and further discussed under environmental indicators in section 3.1.3 (see also Annex 5.4 and Annex 5.5).

The European Union (EU) Marine Strategy Framework Directive (MSFD) addresses plastic litter in the marine environment. The Zero Pollution Action Plan (EC, 2021) defines specific reduction targets for waste generation, plastic litter at sea and input of microplastics, and EEA (2022) considers marine litter in Europe in an integrated assessment from source to sea. EEA (2022) describes socio-economic drivers, such as trends in plastic production, pressures such as generation of waste (from plastic packaging and small non-packaging plastic items) and particularly the mismanaged fraction, and the state of pollution in coastal and marine environments. Policy objectives and targets set out by key European policies, e.g. the 7th and 8th Environmental Action Programme and Waste Framework Directive, are assessed by considering selected indicators. These are included in the DPSIR scheme shown in Annex 5.2. Furthermore, EEA (2022) makes use of existing indicators and data sources, which are defined by frameworks such as OSPAR and HELCOM, see Annex 5.4 and Annex 5.5.

The EU has developed a set of circular economy indicators under the headlines: Production and consumption, Waste Management, Secondary raw materials and Competitiveness and innovation, all of which could relate to the lifecycle of plastics.[2] These indicators are part of the Circular Economy Action Plan (EC, 2020), which provides a product policy framework based on integrated actions from economic actors, consumers, citizens and civil society organizations. The aim is to support the European Green Deal while building on circular economy, supporting sustainable products, services and business models and transforming consumption patterns towards no-production of waste. Plastic is an integral part of this agenda. The Commission will take further targeted measures to address its sustainability challenges and will continue to promote a concerted approach to tackle plastic pollution at the global level. The Commission will also update the Monitoring Framework for the Circular Economy where the circular economy indicators can be found. New indicators will rely on European statistics and take into account the focus areas in this action plan and the interlinkages between circularity, climate neutrality and the zero pollution ambition. Indicators on resource use, including consumption and material footprints to account for material consumption and environmental impacts associated to production and consumption patterns will also be further developed.

The Waste Framework Directive 2008/98/EC and its amendment Directive (EU) 2018/851 lie down measures to protect the environment and human health by preventing or reducing the generation of waste, the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of use. Directive 2008/98/EC on waste and repealing certain directives mentions the development of effective and meaningful indicators of the environmental pressures associated with the generation of waste aimed at contributing to the prevention of waste generation at all levels, from product comparisons at community level through action by local authorities to national measures (Annex 5.3).

Directive (EU) 2019/904 on the reduction of the impact of certain plastic products on the environment, also described in brief as Directive on Single-Use Plastics (SUP), has the objectives to prevent and reduce the impact of plastic products on the aquatic environment in particular, and on human health, as well as to promote the transition to a circular economy with innovative and sustainable business models, products and materials. The directive applies to SUP products, to products made from oxo-degradable plastic and to fishing gear containing plastic. Where easily available and affordable alternatives exist to SUP products, SUPs cannot be placed on the market anymore, including, for examples, plastic cutlery, plates, straws and containers for food and beverages. For other SUP products, limited use is intended, for example through reduced consumption, design and labelling requirements (e.g. plastic caps

[2] https://ec.europa.eu/eurostat/web/circular-economy

attached to bottles) and waste management and clean-up responsibilities for producers. Specific aims include a 90% separate collection target for plastic bottles by 2029. The directive also promotes circular approaches that give priority to sustainable and non-toxic re-usable products and re-use systems rather than to single-use products, aiming to reduce the quantity of waste generated. This is planned by fostering innovative and sustainable business models, products and materials, as well as limitations on SUP products, making alternatives more interesting. The directive holds no specific indicators, but focus and target areas are included in Annex 5.2.

Directive 94/62/EC on packaging and packaging waste has the objectives to harmonize national measures on the management of packaging and packaging waste in order to prevent or reduce any impact on the environment, thus providing a high level of environmental protection. These measures are directed at preventing the production of packaging waste and at enhancing re-use and recycling of packaging waste, and hence, to reduce the final disposal of packaging waste. No specific indicators are stated, but measures and aims are included in Annex 5.2. The directive is currently being revised to comply with the ambitions of the European Green Deal and the Circular Economy Action Plan, aiming at fully recyclable and reusable packaging by 2030. This action includes new targets for waste reduction, recycling and reuse.

Microplastics are intentionally added in a range of products and applications, such as artificial turf sports pitches. A wide-ranging restriction has been proposed on microplastic in products placed on the European market to avoid or reduce their release to the environment (ECHA, 2020). No specific indicators are suggested. However, the European Commission has also launched an initiative to address the unintentional release of microplastics in the environment, as part of its Plastic Strategy and the Circular Economy Action Plan (EC, 2020).

3.1.3 Environmental indicators

State and impact indicators for various parameters that are currently in use and that can be considered relevant for macro- and microplastic in the marine environment are listed in Annex 5.3. The indicators are proposed by a number of organizations and initiatives on local, regional and global scales, that specifically address plastics, but also by frameworks that allow for disaggregation of plastic data. Table 1 aggregates the indicators in Annex 5.3.

Environmental indicators should be scientifically valid, easy to understand by a variety of stakeholders, sensitive and responsive to change, cost-effective; and policy relevant (GESAMP, 2019). Core (or primary) environmental indicators are often agreed on at the regional level (e.g. within RSCAPs) where consensus has been reached regarding methods with associated harmonized guidelines, protocols and QA/QC procedures, and which can be implemented immediately. Core indicators are used to initiate national activities and activities on a regional scale.

Candidate (secondary) indicators have typically not reached the same broad consensus and lack guidelines for the suggested methods or supporting QA/QC procedures. Further efforts are usually needed for candidate indicators to develop methodologies before they are implemented at regional and global levels. Secondary monitoring indicators may also serve other specific monitoring purposes, e.g. effect monitoring in relation to chemicals associated with plastic pollution.

UNEP (2022b) includes a summary of the environmental indicators in RSCAPs. It states that 14 action plans have developed associated indicators, while two more action plans highlight that their indicators still need to be developed (UNEP, 2022b). **Table 2** lists the environmental indicators that are suggested in the individual RSCAPs and thus details what is summarized under "State" in Table 1.

Table 2: Environmental indicators included in action plans of the Regional Seas Conventions.

Action Plan	Biota	Beach litter	Seafloor litter	Microplastics	Water column and/or floating litter	Implementation actions defined
Regional Plan on Marine Litter Management in the Mediterranean	X	X	X	X	X	X
PERSGA – Regional Action Plan for the sustainable Management of Marine Litter in the Red Sea and Gulf of Aden		X	X		X	X
PAME- Regional Action Plan on Marine Litter in the Arctic*	X	X		X		X
OSPAR – Regional Action Plan for Prevention and Management of Marine Litter in the North-East Atlantic	X	X	X	X		
Black Sea Marine Litter Regional Action Plan	X	X	X	X	X	X
HELCOM Regional Action Plan for Marine Litter in the Baltic Sea	X	X				X
Commission for the Conservation of Antarctic Marine Living Resources	X	X				
NOWPAP Regional Action Plan on Marine Litter		X	X	X		
Western Ocean Regional Action Plan on Marine Litter (WIO-RAPMaLi)		X				X
Regional Action Plan on Marine litter Management for the Wider Caribbean Region		X				
SPREP – Pacific Regional Action Plan Marine Litter						X
ASEAN Framework of Action on Marine Debris						X
Abidjan Convention						X
TEHERAN Convention – Caspian Sea						X

*Indicators proposed by the Arctic Monitoring and Assessment Programme (AMAP), see text for details.

The Regional Action Plan of the Protection of the Marine Environment in the Arctic (PAME, 2021) is supported by indicators proposed by the Arctic

Monitoring and Assessment Programme (AMAP, 2021a), both working groups under the Arctic Council. The primary environmental indicators developed by AMAP (2021a; 2021b) include biota (seabirds), beach litter and microplastics (in water and/or sediment). Secondary indicators, which are considered less mature for environmental monitoring, include air/atmospheric deposition and biota (fish, invertebrates).

3.1.4 Databases

Several databases exist hosting national and international datasets for plastics in the environment. The datasets can represent research data (e.g. the online portal LITTERBASE; Bergmann et al., 2017), citizen science data (e.g. Debris Tracker[3]; Marine LitterWatch[4]) and data from monitoring programmes. As summarized in Provencher et al. (2023), databases for monitoring data on beach litter are hosted by OSPAR and by the National Oceanic and Atmospheric Administration (NOAA) of the USA. The database of the International Council for the Exploration of the Sea (ICES) enables storage of data on seabed litter. The G20 initiative of the OECD has established a global database for floating microplastics. Attempts to extend existing databases are ongoing, as also discussed in section 3.3.2. **Table 3** includes examples of databases of different geographical scales. Ideally, these levels should be connected, i.e. a dataflow should go from the local to the global level. In practice, data are entered at all levels without interlinkages.

Table 3: Examples of databases and users on different geographical scales.

Geographical scale	Examples of databases	Users and types of data
Global	Global Partnership on Marine Litter (GMPL)	UN organisations, e.g. UN Environmental Programme (UNEP), International Maritime Organization (IMO), Food and Agricultural Organisation (FAO)
Regional	EMODNET	EU
	ICES	Research and monitoring projects, data on seafloor litter
	OSPAR	Regional Seas Convention, Research and monitoring projects, data on beach litter and seabirds
	Marine Litter Watch	Citizen science data
	LITTERBASE	Research data
National	Marine Debris Monitoring and Assessment Programme (MDMAP)	US Environmental Protection Agency; US National Oceanic and Atmospheric Administration (NOAA)
Local	Data collected by cities and municipalities, e.g. on mismanaged waste, plastic leakage from wastewater and stormwater	

3.2 Indicators for leakages along the value chain and for the lifespan of plastics

3.2.1 General remarks

This section provides a synthesis of the most recent studies that have sought to estimate plastics leakage to the environment across the full plastics value chain and on the global scale. We have identified three key studies by OECD (OECD, 2022a, 2022b), Lau and colleagues (Lau et al., 2020; SYSTEMIQ & The

[3] https://debristracker.org/

[4] https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/marine-litterwatch

Pew Charitable Trusts, 2020) and UNEP (Ryberg et al., 2019; UNEP, 2018). We have, per default, used the most recent estimates from (OECD, 2022a, 2022b) and report these. However, important findings from the two other studies have also been included. Moreover, we have included estimates and findings from other studies where relevant.

In general, the three studies use similar approaches to estimate plastics leakages, however, they differ for certain key model assumptions. The OECD report presents a comparison of key estimates in the studies with relation to plastic use as well as waste generation and treatment and concluded that the studies gave similar results at an overall level, considering the high uncertainty that accompanies these estimates (Table 4).

Table 4: Comparison of estimates for global plastic use, plastic waste generation, and mismanagement of plastic waste across three different studies.

Model key figure	Amount for 2015/2016 [million metric tonnes]	Reference
Global plastic use	388	Ryberg et al. (2019); UNEP (2018)
	413 (460 in 2019)	OECD (2022a; 2022b)
Global plastic waste generation	161	Ryberg et al. (2019); UNEP (2018)
	220	Lau et al. (2020); SYSTEMIQ & The Pew Charitable Trusts (2020)
	308 (353 in 2019)	OECD (2022a; 2022b)
Global total mismanagement of plastic waste	41	Ryberg et al. (2019); UNEP (2018)
	91	Lau et al. (2020); SYSTEMIQ & The Pew Charitable Trusts (2020)
	74 (82 in 2019)	OECD (2022a; 2022b)

OECD (2022a) developed complete estimates of plastic production, use, and waste management as well as leakages to the environment (**Figure 2**). Moreover, the OECD study also provides estimates of the fate of plastics in the environment and the amounts that are transported to rivers and lakes, and to the marine environment. Estimates of the accumulated stock are also provided.

According to OECD (2022a), the societal in-use stock was 3120 Mt in 2019, of which about 139 Mt (4.5% of the societal stock) were accumulated in rivers, lakes, and oceans. Furthermore, while 460 Mt of plastics were used in 2019, 6.3 Mt and 13 Mt of macroplastics were lost to the aquatic environments (lakes, rivers and oceans) and terrestrial environments, respectively. Additional 2.7 Mt of microplastics were lost to the environment. In total, approximately 4.8% of the annual amount of plastic use is released to the environment.

The following sections will provide further details on the plastic use and waste management and on the main sources of plastic leakage across the plastics value chain. It is important to analyze if meaningful indicators for plastic pollution exist in these upstream processes, closer to the sources of plastic pollution. Indicators in the plastic value chain could show effects of potential management efforts. They could also be linked to environmental indicators for a better process understanding, in the context of the DPSIR framework, and for an evaluation of effectiveness of management actions on downstream processes.

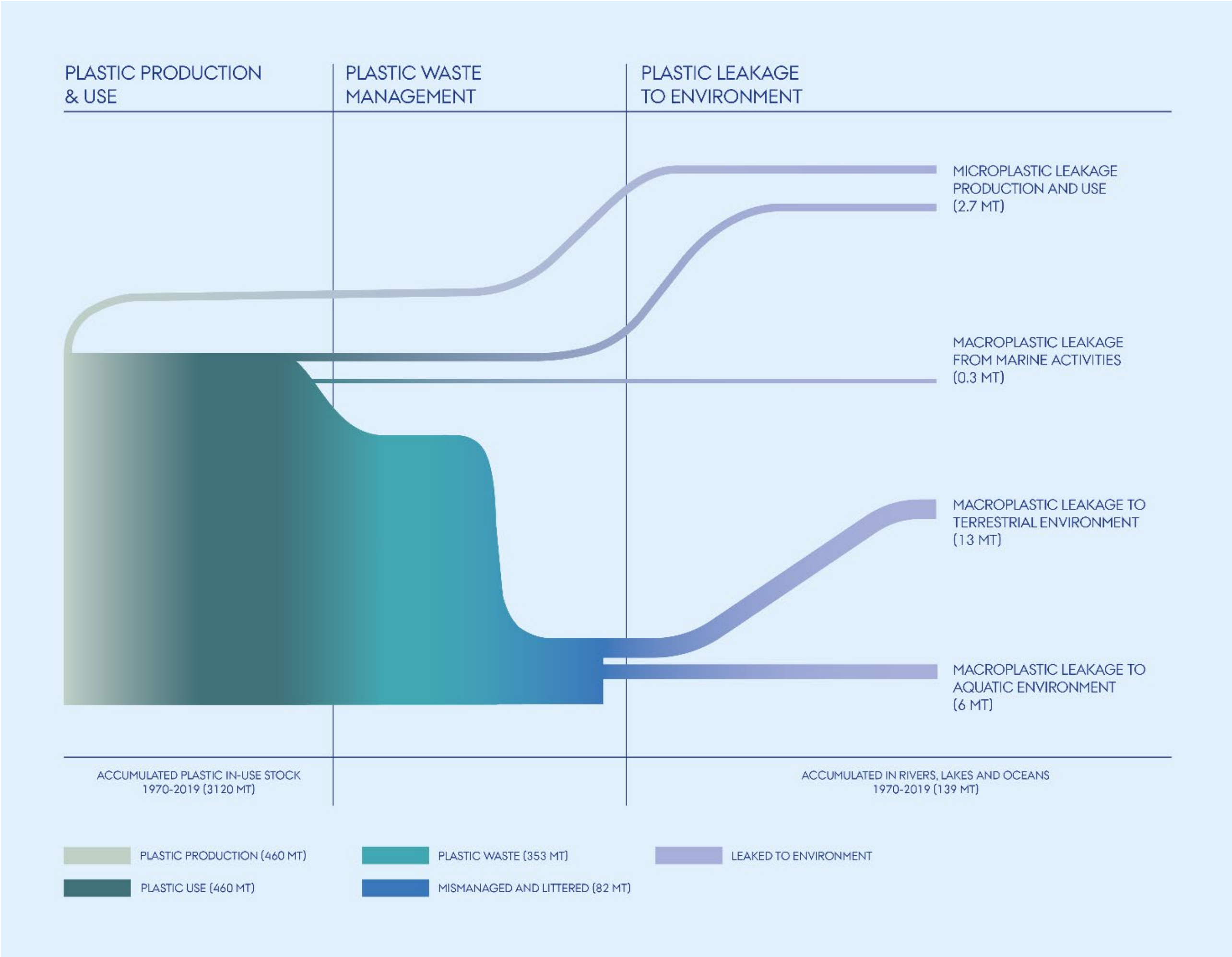

Figure 2: Global plastics flows in 2019, focusing on plastic production and use, plastic waste, and plastics in the environment. Accumulated stocks refer to amounts accumulated from 1970 to 2019. The figure is modified from OECD (2022a).

3.2.2 Plastic use

Plastic use has increased steadily since 1950, and the annual global production of plastics was 460 Mt in 2019 (Geyer et al., 2017; OECD, 2022a). The amounts of plastics being used is projected to triple around 2060, based on a "business as usual" scenario (OECD, 2022b). The majority (approximately 46%) of plastic used in 2019 was used in OECD countries in America and Europe. Another 20% and 15% of plastic use was in China and the rest of Asia, respectively. Further information on the use of plastics by world region, polymer type, and plastic application can be found in Annex 5.6.

Figure 3: Overview of global plastics use split into world regions. World map is Image by rawpixel.com on Freepik.

According to OECD (2022a), most plastics are used for packaging followed by use in construction and in transportation (**Figure 4**). The main polymers used for different types of application are shown in **Figure 5**. Polyethylene (PE) as high density PE (HDPE), low density PE (LDPE) and linear LDPE (LLDPE) are the main polymers in packaging, accounting for almost 50% of total packaging plastics. This is followed by polypropylene (PP; 26%) and polyethylene terephthalate (PET; 17%). The most dominant polymers in construction are polyvinylchloride (PVC) and PE with 47% and 18%, respectively. The construction industry also uses several special plastics for various specialized applications.

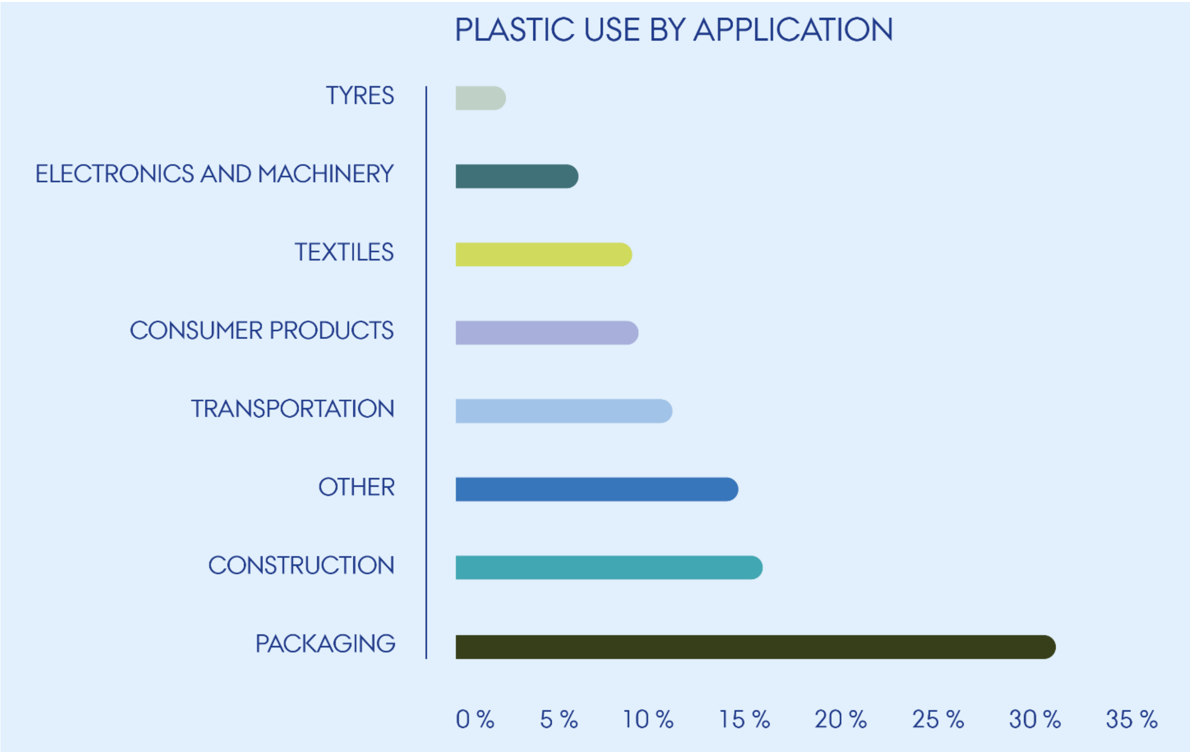

Figure 4: Relative plastic use in 2019 by application, based on data in OECD (2022a).

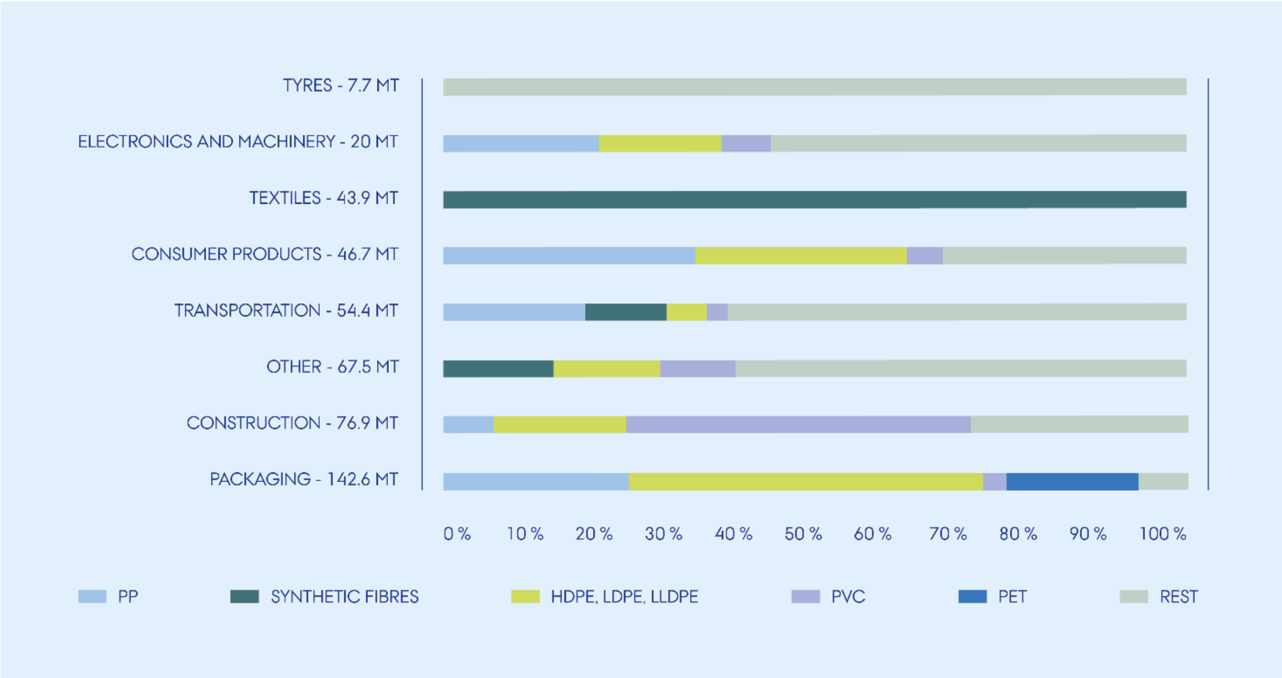

Figure 5: Plastic use in 2019 by application and polymer type, based on data in OECD (2022a). PP: Polypropylene. HDPE: High density polyethylene. LDPE: Low density polyethylene. LLDPE: Linear low density polyethylene. PVC: Polyvinylchloride. PET: Polyethylene terephthalate. "Synthetic fibres" are fibres made of different polymers, used in textiles and other applications. "Rest" includes polystyrene, polyurethane and other polymers, such as (styrene) butadiene rubber used in car tyres.

3.2.3 Plastic waste generation and treatment

Plastic waste generation generally follows plastic use trends. It is clear to see that the per capita plastic waste generation varies greatly among regions. The largest per capita generation is seen in high income countries that also have a large per capita use of plastics (**Table 5**).

Table 5: Plastic waste generation in 2019. Shown as total plastic waste generation and generation per capita. Data from OECD (2022a).

Region	Plastic waste generation [Mt]	% of total	Plastic waste generation [kg/cap]
OECD America	91	26%	161
OECD Europe	67	19%	114
China	65	19%	47
Other Asia	44	12%	18
Middle East and Africa	33	9%	21
Other America	19	6%	43
Eurasia	19	5%	55
OECD Pacific	14	4%	68
Total	353	100%	46

About 50% of the plastic waste generated is related to packaging (40%) and various personal, consumer and institutional products (12%) (**Figure 6**). Both categories have relatively short product lifetimes with an average of 0.5 to 3 years, respectively (OECD, 2022a). Hence, these products are likely to be produced, used, and disposed of within a year. The polymer composition of waste for these two categories is shown in **Figure 6**. This clearly shows that most of the waste results from PP, PE, and PET products. Thus, placing a focus on these polymers in these plastic applications appears relevant when targeting the largest mass amounts of plastics waste, as further discussed in section 3.3.3.

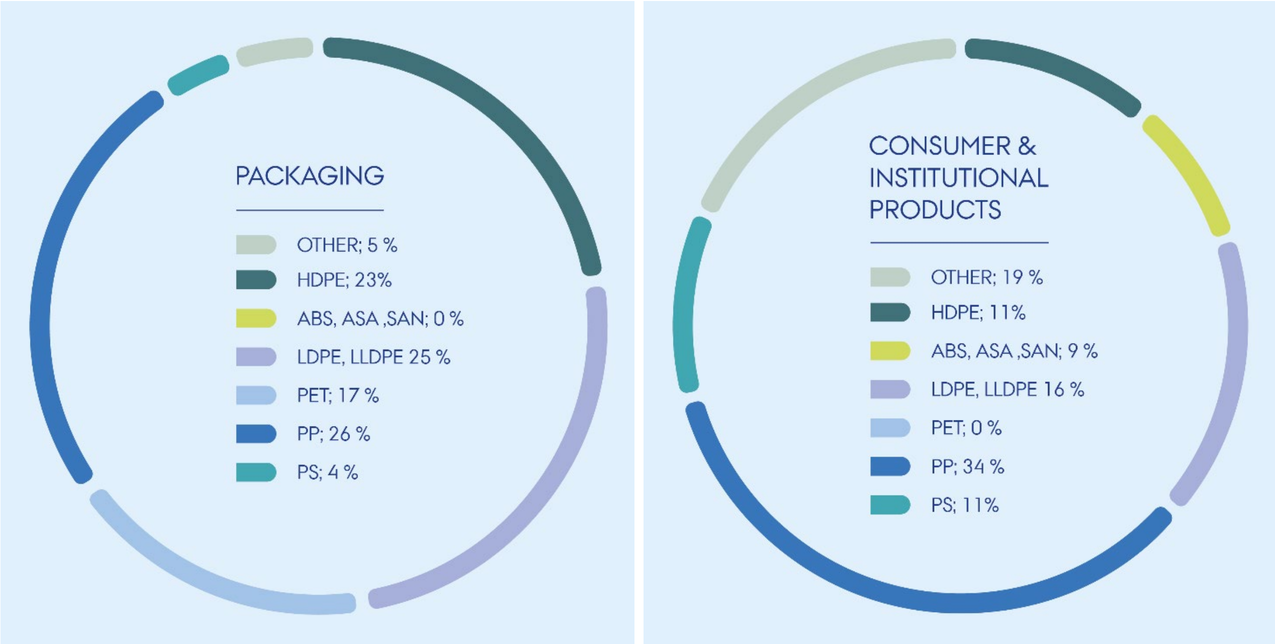

Figure 6: Polymer composition of plastic waste for Packaging and Consumer & Institutional Products, based on data in OECD (2022a). HDPE: High density polyethylene. ABS: Acrylonitrile butadiene styrene. ASA: Acrylonitrile styrene acrylate. LDPE: Low density polyethylene. LLDPE: Linear low density polyethylene. PET: Polyethylene terephthalate. PP: Polypropylene. PS: Polystyrene.

In terms of plastic waste treatment, we see large variations among regions. While only about 6% of the plastic waste in OECD countries is considered mismanaged or littered, 37% of the plastic waste is considered mismanaged or littered in non-OECD countries (OECD, 2022a). The largest percentage of mismanaged waste relates to plastic waste in Africa, Asia and Latin America (**Figure 7**). Addressing this would be particularly efficient, as further discussed in the recommendations in section 3.3.3.

Mismanagement refers to poor handling of the plastic waste, such as open dumping where the waste can be released to the environment. The amount of waste released to the environment due to mismanaged waste is highly uncertain and relies on best estimates that can range from 10% to 70%. The uncertainty is linked to a lack of monitoring data on the leakage. Naturally, the mismanaged waste, such as waste dumped near or in water bodies, is not part of the formal waste management system and is therefore not regulated. Moreover, leakages from different dump sites are likely to vary considerably due to their different characteristics, such as proximity to water and use of crude mechanisms for containing waste, such as fences.

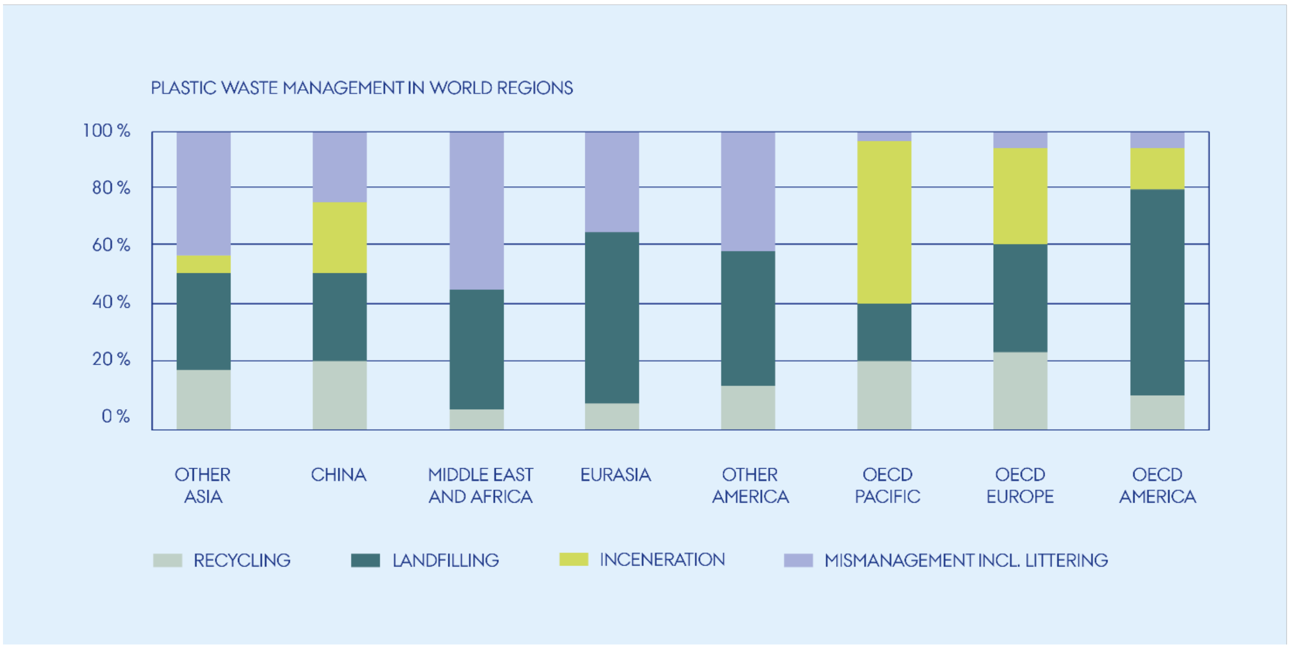

Figure 7: Share of plastics treated by waste management category in 2019, before recycling losses, based on data in OECD (2022a).

3.2.4 Leakage across the plastics supply chain

Based on OECD's global plastic outlook report (OECD, 2022a), total amount of plastics lost to the environment was estimated to be 22.1 Mt in 2019. As stated in section 3.2.1, this consisted of 19.4 Mt of macroplastics from mismanaged plastics and littering and 2.7 Mt of microplastics from plastics production and use.

Given the uncertainty of the estimates, this leakage from mismanaged plastics and littering can range from 13 Mt to 25 Mt, or even more. Indeed, while an increasing number of studies confirm that plastic leakage is an environmental issue, the exact estimates differ among studies. This is mainly due to differences in the modelling approaches and to the assumptions made to generate plastic leakage estimates. A comparison of leakage numbers presented in some of the main studies in this field (Borrelle et al., 2020; Jambeck et al., 2015; Lau et al., 2020; Lebreton et al., 2017; OECD, 2022a; Ryberg et al., 2019) is shown in **Figure 8**. The comparison also shows that the OECD estimates are close to the middle of the individual estimates, thus not representing extreme cases, but rather a best estimate.

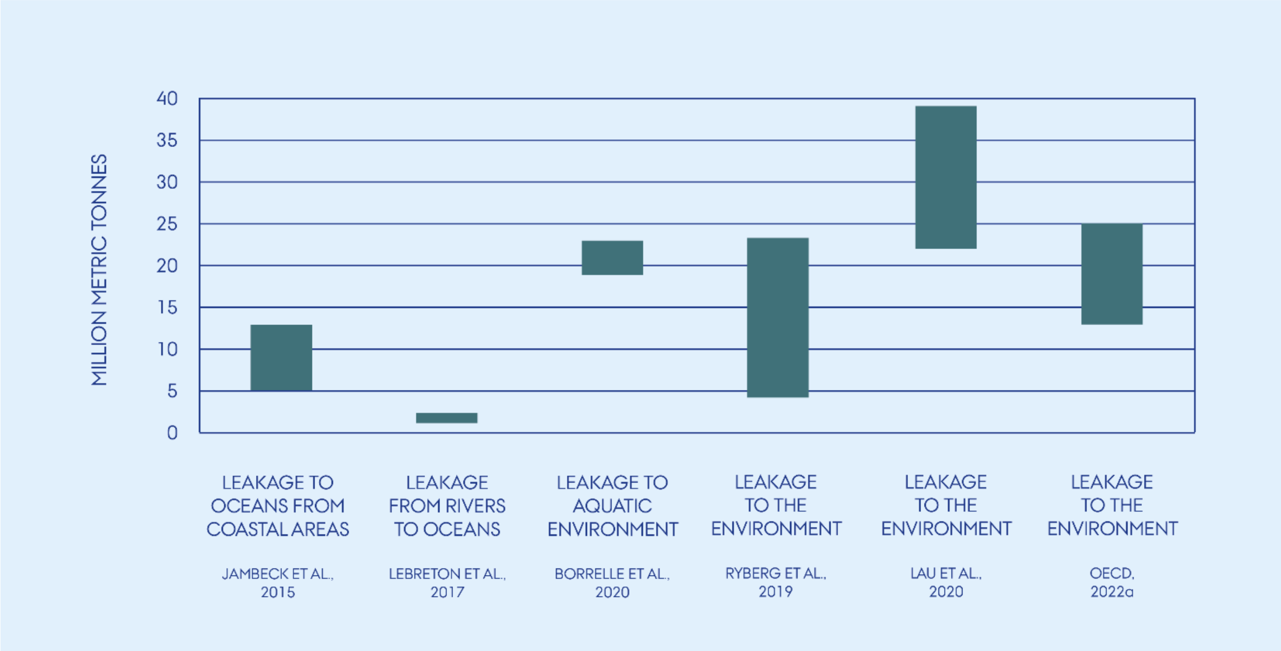

Figure 8: Comparison of estimates of plastic leakage from mismanaged waste and littering (OECD, 2022a), in key studies in the field. Note that the type of estimate and its coverage is not identical across studies

While a large part of the plastic usage occurs in high-income OECD countries, most of the plastics leakage is from emerging low- to middle-income countries, with 69% from Asia, the Middle East and Africa. This is in accordance with the study by Jambeck et al. (2015) who also described these areas as those with the highest plastic leakage. As shown in **Figure 9**, macroplastic leakage accounts for most (approximately 88%) of the total global plastics leakages. Thus, on a mass basis, focus should be on reducing macroplastics.

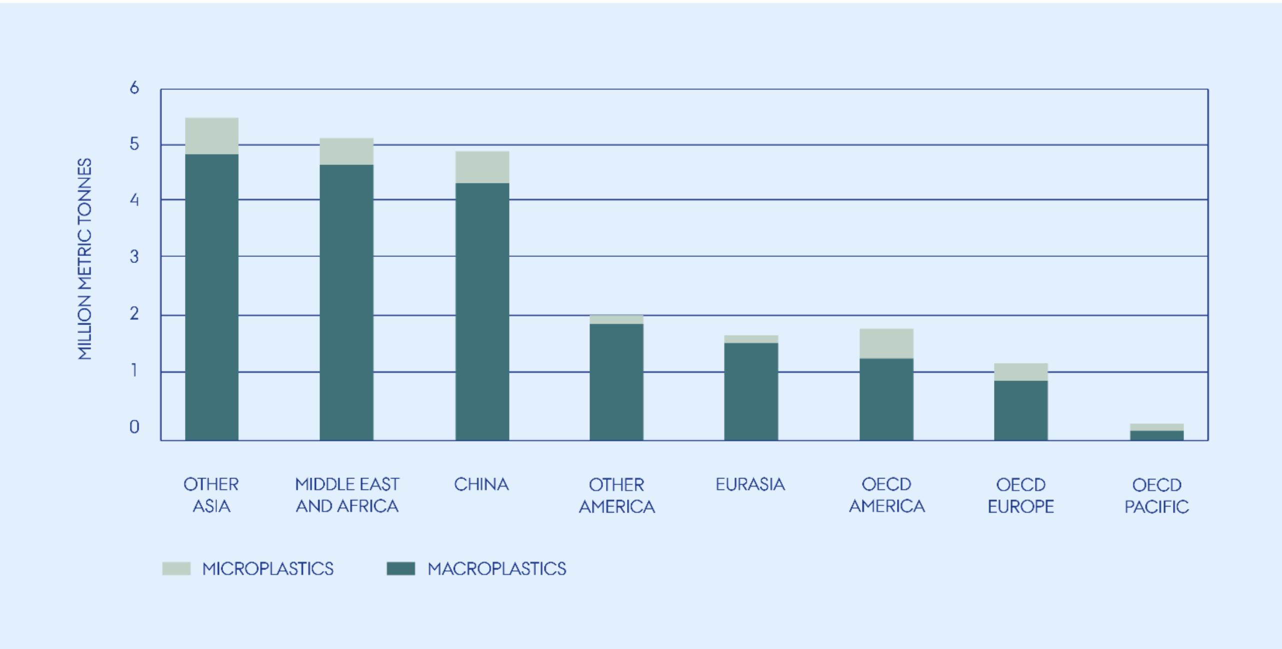

Figure 9: Plastic leakage from different world regions in 2019 (OECD, 2022b).

Macroplastic waste will undergo transformation in the environment and be fragmentated into microplastic particles. Consequently, the most important source of microplastics is likely the degradation of macroplastics in the environment. Given that the major source of plastics in the environment is mismanaged plastic waste, in particular in emerging low- and middle-income countries, indicators are needed that focus on proper waste management of macroplastics in these countries, as further discussed in section 3.3.3. By extension, this will also include microplastics, with the breakdown of macroplastics as the main source.

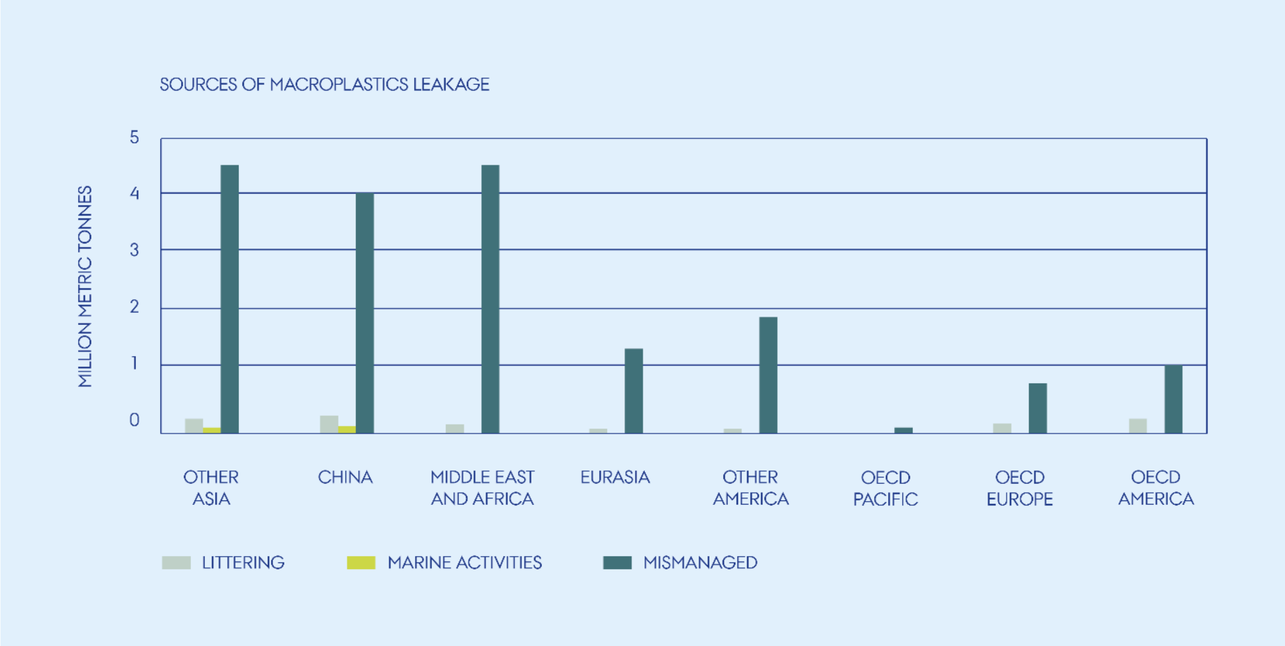

Figure 10: Sources of macroplastic leakage to the environment (terrestrial and aquatic leakage), based on data in OECD (2022a).

As described in section 3.2.3, most of the plastics leakage from mismanaged waste is comprised of Packaging and Consumer & Institutional Products with the main polymers being PP, PE, and PET. This is also the case for the mismanaged plastics waste leakage from Other Asia, China, and Middle East and Africa.

The second most important source of macroplastic leakage is the littering of end-of-life plastic products (1.1 Mt). Waste littering is a large issue and relates to plastics being thrown away by citizens and not correctly disposed by consumers (OECD, 2022a). The exact amounts of plastics that are littered globally each year are highly uncertain due to poor monitoring of littering. However, studies on e.g. ocean clean-ups show that plastics or plastic-containing consumer products are often found on beaches due to littering. Beach litter data collected in several countries could be a relevant starting point to assess trends and effects of regulations, such as the EU Directive 2019/904 on SUP plastics. Moreover, a large part of sweepings in cities contain plastic littering, such as cigarette buds and various types of plastic packaging and wrapping.

Fishing activities and other marine activities also contribute substantially to the leakage of macroplastics due to the loss or discarding of nets at sea, the abrasion of other fishing gear such as dolly ropes and other non-netting waste (0.26 Mt). The leakage estimates for marine activities are highly uncertain and will be further discussed in Section 3.2.5. This is important as there is reason to believe that leakage from marine activities is more problematic per kg plastics released due to the longer environmental lifetime of plastic materials that are specifically designed to be used in marine environments. In addition, detrimental effects on marine wildlife have been associated with the entanglement in fishing gear, and the issue of "ghost fishing" has been described as a global problem (NOAA, 2014; Lively and Good, 2019). Thus, although the contribution to the total amount of plastics is small, its ecological effects can be substantial.

Figure 11: Sources of microplastics leakage to the environment (terrestrial and aquatic leakage), based on data in OECD (2022a).

Total microplastic leakage added up to 2.7 Mt in 2019, 35% of which was generated in OECD countries. The largest source of microplastic leakage is from road transport including tyre abrasion (0.7 Mt), brake wear (0.05 Mt) and eroded road markings (0.2 Mt). Another source of microplastic release is the "dust" from the abrasion of shoe soles (Lee et al., 2022; OECD, 2022a), paint wear from interior and exterior surfaces, losses from construction and demolition activities and household textile dust (in total 0.8 Mt). The losses of plastic pellets from production processes and from artificial turfs account for 0.28 and 0.05 Mt, respectively (OECD, 2022a), i.e. a non-negligible, but not the greatest contribution to the overall loss of microplastics.

It is important to note that while these leakages are estimated to be the dominant microplastic losses, these microplastics are not commonly found in the oceans (OECD, 2022a). This might be unexpected and could have several reasons. For instance, vulcanized rubber used in tyres was not originally considered microplastic material. It is likely to sink to the bottom of the oceans and will not be found in samples taken from the water surface. It is also possible that microplastics from abrasion are so small, that they are below the detection limit in sampling of marine microplastics. Finally, it is possible that the plastics are accumulated elsewhere, e.g. in soils before reaching the oceans (UNEP, 2018). In general, the lack of harmonized methods has been an obstacle in monitoring of tyre abrasion particles (Wik and Dave, 2009).

3.2.5 Plastic losses from marine activities

Direct leakages of plastics from marine activities are generally poorly accounted for in global plastic leakage models. Monitoring data on leakage are generally dated, scarce or completely absent. Still, it is likely that losses from marine activities are important as they are directly lost to marine environments and cause effects there. Moreover, they are designed to last in marine environments, hence they are likely to stay in the marine environment for an extended time.

Direct leakage of plastics to sea can be from:

- Fisheries and aquaculture: Maintenance and repairing damaged nets at sea, general abrasion of nets, ropes and strings, abandoned, lost or otherwise discarded fishing gear (ALDFG), i.e. nets, pots, ropes etc., and loss of different types of equipment and user plastic products including galley waste.
- Commercial shipping and offshore activities (merchant shipping, ferries, cruise liners, military fleets, offshore constructions), galley and grey waste disposal at sea, loss of cargo/containers, equipment and user plastic on board, abrasion of equipment on board.
- Recreational activities at sea, e.g. boating: loss of user plastic incl. galley waste, abrasion of ropes and strings.

While significant progress has been made in quantifying the amounts of land-based sources of marine litter, less information exists for sea-based sources including ALDFG (Jambeck et al., 2015; Lebreton et al., 2018). With regards to ALDFG, this is largely due to the challenges arising from the focus on different gear types and/or geographic areas in the literature (GESAMP, 2021; Richardson et al., 2019). In addition, one major challenge in comparing ALDFG estimates on a regional or global scale is the lack of a harmonised reporting system.

The often-referred estimate that 640,000 tonnes of ALDFG enter the ocean annually has been incorrectly cited for over a decade (Richardson et al., 2021) and is unfortunately still being used (seame.net). This number was traced back to a 1975 publication by the USA's National Academy of Sciences, which stated that roughly 6.4 million tonnes of marine litter entered the ocean every year (NAS, 1975; Richardson et al., 2021). This estimate included sources of marine litter from passenger vessels, merchant ships, recreational boats, commercial fishing vessels, military vessels, oil and drilling platforms and catastrophic events (NAS, 1975). Another publication provided a rough estimate of < 10% of marine litter being ALDFG, by volume (Macfayden et al., 2009). Later publications incorrectly turned this into an annual input mass of 640,000 tonnes of ALDFG.

A recent study has attempted to estimate the global loss of fishing gear (Richardson et al., 2019) and found that 5.7% of all fishing nets, 8.6% of all traps, and 29% of all lines were lost around the world each year, but did not provide mass estimates. Depending on the type of fishing gear, masses will vary considerably. As very little or no information exists from the Southern Hemisphere, this estimate is skewed towards the Northern Hemisphere. Thus, as of 2022, we still have no reliable information on the amount of ALDGF entering the marine environment on a global scale. The importance of acquiring this information has been recognized by several organizations, and efforts to provide solutions have been initiated by the Food and Agricultural Organization (FAO) of the United Nations, UNEP and the International Maritime Organization (IMO). A significant positive association between fishing effort and gear loss has been found in the Arafura Sea-Gulf region (Richardson et al. 2018 and references therein).

Another gap in our knowledge regarding ALDFG in the marine environment is information from recreational fishing. In spite of a high number of people fishing recreationally around the world, no estimates of ALDFG resulting from this type of fishing exist (Drinkwin, 2022). Presumably, the share will be small compared to losses from commercial fishing, but it remains to be quantified.

Despite the steady increase in the production of seafood for human consumption (FAO, 2018; GESAMP, 2021), information about the global amount of plastic pollution entering the marine environment from aquaculture is missing (FAO, 2017; GESAMP, 2021). This is mostly due to the lack of appropriate observation and monitoring systems at the national or regional level (Skirtun et al., 2022). In addition, there are currently no requirements or standardized processes for aquaculture farms to monitor gear loss (FAO, 2017; Huntington, 2019; Skirtun et al., 2022). However, regional data and assessments do exist. For example, in the European Economic Area, gear and debris loss associated with aquaculture is grossly estimated to be in the range of 3,000-41,000 tons annually (Sherrington et al., 2016).

Shipping vessels (including fishing vessels) generate waste daily (e.g. wire straps, plastic sheets, sewage). The discharge of garbage and sewage is regulated by the International Convention for the Prevention of Pollution from Ships (MARPOL) of the IMO. However, the waste may end up in the marine environment due to mismanagement (either at sea or at reception facilities in ports) or unfavourable weather conditions (GESAMP, 2016). The type of waste generated from shipping is relatively well known, but few detailed studies exist on the amount of plastic waste (GESAMP, 2021). GESAMP (2021) made a best estimate of what is (potentially) discharged at sea by developing an alternative approach, a 'waste gap' calculation. A waste gap calculation is defined as the gap between the waste expected to be generated onboard the ship (and the part expected to be delivered in ports), and the waste actually delivered in ports.

A significant number of containers are lost at sea every year, adding to marine pollution. In 2020/2021 an average of 3.113 containers were lost at sea (WSC, 2022) which is an increase from previous years. Although it is unknown how many contained plastics, it has been argued that many goods transported by cargo ships contain plastics and that microplastics in the oceans could be related to lost pellets (Jo, 2020). Furthermore, given the increase in maritime transport and an associated increase in container ship accidents (Wan et al., 2022), this leakage source may deserve more attention.

3.2.6 The lifespan of plastics and the fate of plastics in the ocean

One of the primary properties of plastics is their durability. Thus, they persist in the environment long after they have been introduced. The understanding of the life cycle and end-of-life fate of plastics is very limited. Depending on the type of plastics used to manufacture a product, the breakdown process in the marine environment will vary, further influenced by variations in environmental conditions (Arp et al., 2021). Plastics made of HDPE (e.g. buoys) and PVC (e.g. pipes) are chemically resistant and therefore take longer to fragment and abrade, whereas expanded polystyrene (EPS, e.g. insulation boxes) breaks into small pieces more easily. Moreover, actual degradation of the plastics in the environment also varies greatly among plastic application and polymers. For instance, Chamas et al. (2020) estimated plastic half-lives of 58 years and 1200 years for HDPE plastic bottles and HDPE pipes, respectively. This is mainly due to different physical characteristics of the plastics, such as thickness of the plastic.

Depending on their density, and possibly degree of biofouling, some plastic types will float on the surface, whereas other types will sink. The distribution in the ocean will have implications for physical and chemical weathering. It is therefore important to differentiate between different types of plastics in research and monitoring campaigns to improve the understanding of their fate in the environment.

3.3 Gap analysis, recommendations and outlook

3.3.1 General remarks

The indicators in the DPSIR framework cover significant parts of the plastics value chain. Indicators representing Drivers, Pressures and Responses are largely covered by global initiatives, including those by UNEP, OECD and the SDGs. Indicators representing State and Impact are generally addressed at the regional or national level, however, also in combination with global settings. The local geographical level is hardly represented in the current indicator landscape and might require adaptations in monitoring and impact considerations, depending on local conditions.

In the following, recommendations are given for possible indicators, including new and further developments. A summary of potential new, not fully developed indicators with their advantages and disadvantages is given in **Table 6**. These consider different stages of the lifespan of plastics, including both plastic leakages and the state in the marine environment. We have based the recommendations on the following criteria (EC-JRC, 2010; Persson et al., 2022):

- Relevance: Is the indicator relevant for expressing the overall problem of marine plastic pollution?
- Measurability: Can the indicator be measured relatively easily and at reasonable costs? Is it possible to monitor developments over time? Can policy targets be set for the indicator?
- Comprehensiveness: Does the indicator present a broad and comprehensive reflection of the problem of marine plastic pollution?

A summary of the indicators we consider most recommendable, based on these discussions, is given in **Table 7**.

3.3.2 Gaps and challenges

As summarized in section 3.2, estimates have been established for the loss of plastic from the value chain, resulting in an overall leakage of plastic to the environment of 22.1 Mt in 2019. This number includes several assumptions with associated **uncertainties** as well as extrapolations and aggregations of different sources of information. This process is not always fully transparent, and data aggregation might lack standardization. While production numbers are relatively well-known, uncertainties related to the plastic loss from mismanaged waste are considerable. Therefore, it is important to note that the numbers currently available for this type of leakage are estimates that present an order of magnitude, but not a precise measurement. This has implications for the usefulness of indicators for e.g. time series. If uncertainties are large, it will be difficult to detect statistically significant changes.

Since this report combines leakages from the plastic value chain and plastic occurrence in the environment, it becomes apparent that these **approaches have been disconnected** and lack a common denominator. In many cases, indicator data for leakages from production, use and waste cannot directly be compared with or linked to indicator data for occurrence, composition and fate in the environment. Two main reasons are different geographical scales and different reporting units.

While data are available for estimates of the total leakage of plastics to the environment, it is not meaningful to upscale the plastic measurements in the environment in the same way, for example beach litter surveys or water manta trawls. Although there is general consensus that the oceans are a sink of plastics, no aggregated amounts exist, due to the heterogeneity of indicators. For example, beach litter is commonly recorded per item and could be recorded in hundreds of kilograms. Plastics in water manta trawls are usually reported as number of items per volume of water. Converting them to a mass unit would result in a low mass. The same case can be made for sediment measurements. Furthermore, while environmental analyses often include polymer identifications, leakages from the plastic values chains are rarely estimated on a polymer-basis, but rather related to sources or size classes (**Figure 11**). An example of a compilation of polymer-based identification in different indicators is given in **Figure 12**.

Figure 12: Composition of plastics at different stages in the plastic value chain and in the marine environment. Based on Geyer et al. (2017), Erni-Cassola et al. (2019) and Ask et al. (2020)

The reporting of plastic-related data holds a number of inconsistencies that hamper comparability and combination of indicator data. Specifically, no consensus exists on how to report the production of plastics, which can be given as, for instance, mass and type of primary plastics (i.e. pellets) or number of plastic items produced from these pellets. Typical examples of the characterisation of plastic losses are shown in **Figure 10** and **Figure 11**. For environmental indicators, units have generally been specified to make monitoring programmes operational and allow comparisons across space and time (e.g. AMAP, 2021a; 2021b). However, in the determination of microplastics, discussions continue on e.g. lower size limits of detection, also based on the recognition that smaller particles may be particularly relevant from a toxicological point of view.

Two examples of plastic issues that lack connection between losses from the value chain and impacts on the environment are those of tyre abrasion and ALDFG. **Tyre abrasion** has been identified as a significant source of microlitter to the environment (**Figure 11**). Besides the abrasion during use, tyre granulates are also used on artificial grass fields and other surfaces, for example playgrounds. Originally, tyre particles were not frequently included in plastic studies, as they were not considered microplastic particles, also resulting in a pronounced lack of harmonised methods. Furthermore, despite representing a major loss of microplastics to the environment, these particles are not commonly found in marine environmental monitoring (OECD, 2022a). This may be related to strong retainment in the terrestrial or freshwater environment or to an efficient sedimentation in the oceans, probably close to the coast, in estuaries or near wastewater outlets. These processes are not fully understood, but present another mismatch between important potential indicators in the plastic value chain and in the environment.

On the other hand, **fisheries** are a major contributor to plastics in the marine environmental, including the occurrence of ALDFG in sea surface, beach litter and seafloor measurements. However, ALDFG is estimated as a rather small contributor in the global leakage chain (**Figure 10**). Given that fishing takes place worldwide, this points at poor estimates of leakages of ALDFG in the global assessment of plastic losses to the environment. Further monitoring needs are related to cuts from net repair on fishing vessels, which are difficult to quantify. In addition, plastic waste related to fishing gear has an extremely long lifetime as these products are designed for harsh environmental conditions, potentially including time scales from emission to detection that are different from other plastic products.

Although indicators from leakage and environmental indicators have different purposes, it is desirable with some level of consistency and complementarity. In fact, data on upstream leakage and environmental occurrence have the potential of supporting each-other. They can be important in identifying and verifying sources, for example, of the plastic particles detected in the environment. Section 3.3.3 includes examples of environmental state indicators that have the potential to provide information of relevance for assessing trends in leakages from different steps of the plastic value chain.

One major knowledge gap is the plastic leakage to the environment from the **agricultural sector.** Plastics are used extensively in agriculture, for example as protective wraps around mulch and fodder, as cover for greenhouses, to shield the crops and for irrigations tubes, sacks and bottles. Covering products in plastics has increased crop yields, but increasing evidence suggests soil contamination from degraded plastics that can affect biodiversity and soil characteristics. Plastics also enter agricultural soil with fertilizers produced from organic matter such as manure, apparently the major source (UN, 2022). Losses from the agricultural sector could be included in an indicator focusing on riverine inputs.

Other potentially relevant losses to the environment include **container losses** at sea that contain plastics as well as discharges of (micro)plastics with **wastewater** (Sun et al., 2019). Both sources might need more attention for our understanding of plastic sources and pathways. **Ghost nets** could be a potential indicator of ALDGF, perhaps on a mass basis to account for size differences.

While several environmental indicators exist and are incorporated in plastic monitoring programmes, it is important to realize that their representativeness is generally limited. Measurements represent the specific time and location of sampling, and the indicators are specific as well. Beach litter surveys do not provide information on microplastic particles in the water column, for example. For this reason, most organizations have suggested a set of complementary indicators (**Table 2**) including indicators such as seabirds that integrate a certain geographical area. However, it is important to understand what the indicator represents, for a correct interpretation of the data. Furthermore, existing databases could be extended to include data on macro- and microplastics. However, given the complexity of plastics as well as the need for metadata, the expansion of databases is not straightforward, but needs careful consideration (Provencher et al., 2023).

Table 6: Summary of relevant new indicators to be considered for further development

Indicator	Relevance	Challenge	Potential solution
Tyre abrasion	Significant source of microlitter in the environment	Methodological challenges	Inclusion in an integrating indicator such as wastewater or riverine inputs
ALDFG*	Important source of plastic in the marine environment, risk of ecological impacts	Heterogenous parameter, no harmonized reporting system	Already included in beach litter
Container losses	Increasing maritime shipping	No direct link to plastic pollution	Recorded as a general marine pollution issue, not limited to plastics
Wastewater effluents	Source of (micro-)plastics connecting land and sea	Data on sludge needed for mass balance of plastic emissions, costly	Connection to other wastewater measurements
Riverine inputs	Significant input pathway into the marine environment, connecting land and sea, potential for alignment with beach litter measurements	No standardization, costly	Standards from beach litter monitoring could be applied

*Abandoned, lost or otherwise discarded fishing gear

3.3.3 Recommended indicators

Indicators on **plastic production** would mainly be directed at a reduced production of plastics. While a reduction of plastics can be considered the most efficient step towards a decrease of plastic pollution, it might also have counterproductive elements in terms of e.g. mitigating climate change because plastics are often used as a substitute for other carbon-intensive materials, such as glass or metals. A more efficient use of plastics, e.g. by reducing packaging could be most beneficial. Indicators related to plastic production should therefore ideally be defined to increase **plastic use efficiency** rather than substitution of plastics with materials that might have other disadvantages. However, while possibly of lower relevance, plastic production has a better measurability than plastic use efficiency.

The largest mass leakage of plastics is that of macroplastics from mismanaged waste treatment of short-lived packaging and consumer and institutional products made from PP, PE, and PET. We recommend placing more focus on these and developing suitable indicators for covering the **leakage from mismanaged plastic waste**. However, there are some challenges in the data collection:

Ideally, the amount of plastic waste would be monitored that is lost to the environment. However, as discussed in section 3.2.3, mismanaged waste is usually part of the informal waste sector with no regular data collection. Hence, data for this type of indicator will be difficult to obtain. The percentage of mismanaged waste is highest in low-income countries where fewest systematic data collections exist. Alternatively, the losses of plastic waste could be determined from a mass balance, such as

Waste production in the region + Waste imports into the region – Waste exports to other regions = Generated plastic waste

These values could then be compared to data on managed treatment of the plastic waste, with the difference accounting for mismanaged plastic waste. This could be an indicator that could be monitored for increasing or decreasing values over time. However, a challenge with this approach is the determination of the percentages of plastics in the total waste. If the waste is not source-separated, but has a mixed composition, it is difficult to determine the part that consists of plastics. The residual waste fraction is often the part of the waste that is subject to mismanagement as it has little economic value, compared to pure recyclable plastic waste, even though it might contain recyclable or reusable materials. A more straightforward way of determining the extent of mismanaged waste could be a connection to e.g. **beach litter** monitoring, which essentially represents mismanaged and unmanaged waste, as further discussed below.

A possible indicator could also be the **export of plastic products or waste** from high-income countries to low- and middle-income countries to assess the risk of mismanagement of the plastic waste. However, this process is not likely to be of great relevance to indicate leakages from mismanaged plastic waste as the majority of leaked plastics is likely to originate from mixed waste and not from sorted plastics that have an economic value and that are likely to represent the main part of the exported plastic products. Furthermore, rates of export and mismanagement might be decoupled in future developments aiming at improving waste management.

An indirect indicator could be the annual **recycling rate** of plastics. It is indirect because it does not directly reflect plastic pollution. For example, low recycling rates combined with high rates of plastic incineration can still result in low plastic pollution. However, increasing the recycling rate will likely reduce the percentages of plastics that are subject to mismanagement and potential pollution of the environment. Focus should be on the three dominating polymers PP, PE and PET, and data would be needed on their production, import and recycling.

For microplastics, the main leakages relate to the plastics use stage and abrasion and degradation of plastic containing products. The microplastic losses from abrasion are difficult to monitor and regular updates of estimates are not feasible. Potential indicators of **microplastics abrasion** could be air concentrations of plastic dust in urban areas. Indeed, styrene-butadiene rubber (SBR), as used in tyres, has been measured near roads (Wik and Dave, 2009). Increasing air concentrations of plastic dust is likely to be a good proxy of potential further leakages of microplastics to the environment, but might be technically challenging. Microplastics are currently monitored in the marine environment, as further discussed below, integrating over microplastics formed in the oceans from breakdown of larger particles and inputs from land-based sources. An option of connecting microplastics from land, including tyre abrasions, with the marine environment, could be measurements in **wastewater** (as discussed in section 3.3.2), and in **rivers**. The latter could combine macro- and microplastic measurements, but is currently not well-developed or standardized.

As seen in **Table 2**, one of the most widely applied environmental indicators is that of **beach litter**, also commonly described as litter on shorelines. This indicator is relatively easy to implement, but needs a standardized reference framework for unambiguous item identification, quantification and reporting, such as those of OSPAR and HELCOM (Table 2) or of the EU (JRC, 2013). The recent AMAP monitoring plan recommends beach litter, plastics in stomachs of northern fulmars and **microplastics in water and sediment** as priority environmental indicators (AMAP, 2012b). The basis for this recommendation is the technical maturity and feasibility of their measurements, besides a certain complementarity regarding size classes of plastic particles. The EU guidance document for monitoring of marine litter also includes microplastics in water, sediment and biota (JRC, 2013).

Seafloor litter is another widely used indicator (Table 2). Seafloor and beach litter could be most suitable for connection with leakages from the plastic value chain, as mentioned above. However, considering complex accumulation processes on the seafloor, standardized monitoring over time might be challenging. Seafloor litter might thus be most relevant to indicate ongoing accumulations on the ocean floor, including identification of hotspots and impacts on ecosystems.

Microplastic measurements might be able to provide linkages with losses from the plastic value chain as well. Using **biota** as environmental indicators includes measurements in seabirds and turtles that swallow small plastic particles, but also measurements in fish and invertebrates. Using biota as an indicator could create links to exposure and potential impacts. On the other hand, ecological information is needed, for example on feeding habits and migratory ranges, to interpret the data correctly.

As discussed in section 3.3.2, some environmental indicators have the potential to be connected to upstream leakages from different steps of the plastic values chain, for example:

- Trends in occurrence of industrial pellets in e.g. seabirds or on beaches can be linked to leakage from production, transport or use of these plastic materials.
- Source allocations based on compositional analyses of e.g. beach litter or seafloor litter can be used for assessing the likelihood for leakages from different important land- or sea-based sources including waste handling, e.g. by using the so-called matrix scoring techniques on a (sub)regional scale for assessment of the likelihood of leakages from specific types of sources. The matrix scoring technique is a systematic and transparent system that combines litter types, container information and indicator items with multivariate analysis, probability scores and percentage allocations (Tudor and Williams, 2004).
- Direct measurement of leakages based on environmental flux and transport data on plastic amounts and composition in e.g. effluents, stormwater, rivers, air etc.
- Laboratory-based determinations and assessments of polymer composition of micro- and macroplastic particles in the environment can be relevant for comparing data for production and uses of bulk polymers (**Figure 12**).

Although substantial progress has been made in monitoring efforts, there are still challenges with regard to data availability, uncertainties and consequently, the interpretation of the data. It is advisable to work with the same set of indicators in a consistent manner and over a time period. These can be developed into time series, including information on variability that will be important to assess the statistical power of the time series.

Table 7: Summary of recommended indicators for a global agreement.

DPSIR	Indicator	Relevance	Measurability	Comprehensiveness
Drivers	Plastic production	Medium, "Plastic use efficiency" might be more relevant than plastic production, but more difficult to measure.	High, would need to be recorded globally	High
	Plastic use		Medium, needs to combine records on plastic production with export and import data	High
Pressures	Plastic recycling rate	Proxy indicator for mismanaged waste, but with caveats	High, would need to be recorded globally. Needs additional information on other types of management, e.g. incineration, for correct interpretation	Medium, proxy indicator for losses to the environment, uncertainty about other types of waste management
	Plastics in wastewater	High, would connect land-based sources with the aquatic environment	High, could be combined with other parameters measured within wastewater epidemiology. Needs information on domestic sources (wastewater) vs. road run-off (stormwater) for correct interpretation	Medium, no direct connection with the marine environment.
	Riverine inputs	High, could include macro- and microplastics and would connect land-based sources with the marine environment	Medium, may be costly	Medium, processes in the freshwater environment can influence levels in the marine environment
State	Beach litter	High, integrates mismanaged waste and plastic emissions without management measures	High, relatively well-standardized, no need for advanced equipment	High, but difficult to extrapolate from individual measurements
	Floating microplastics	Medium, high fluctuation	Medium, relatively well-standardized, requires equipment for sampling and analysis	Medium, misses particles that do not float (e.g. tyre abrasion)
Impacts	Seabirds/Turtles	High, can provide links to food webs	Medium, relatively well-standardized, requires access to samples and equipment for analysis	Medium, related to animal ecology, represents micro- and mesoplastics

3.3.4 Outlook

The current indicator landscape is fragmented in its attempt to cover all aspects related to plastics as an environmental problem as well as all relevant geographical scales. Useful indicators exist, and recommendations have been put forward in section 3.3.3, together with discussions of their possibilities and limitations. However, future efforts should be directed at a more holistic picture that combines different types of indicators. In addition, the lack of harmonization and standardization is still an issue, both at the data collection and reporting stage. While this has generally been recognized, and multiple initiatives are trying to overcome these lacks, they usually focus on one area of plastic pollution, for example the environmental indicators. Here, more connections should be ensured as well.

It is also important to recognize that the current attempts towards more harmonized and standardized measurements should include questions of data reporting. Efforts to incorporate plastic data into existing databases are ongoing, but hampered by the complexity of plastics as an environmental parameter and the unclear indicator situation. It will be an important element of the development of globally applied indicators to provide adequate database structures. An important detail is an agreement on units for measurement. Plastics can be measured as items or on a mass basis, in fluxes or concentrations. Different indicators can be complementary in this regard, but consistency within one indicator type should be ensured.

The legally binding global agreement to end plastic pollution is a milestone. However, it is strongly dependent on reliable, robust and meaningful data on the global scale. Experience exists from other UN frameworks, such as the Stockholm Convention on Persistent Organic Pollutants (POPs) that has defined POPs in air, human blood and human milk as global indicators (besides perfluoroalkyl substances in water). This experience also shows that the agreement on indicators has to be followed by practical aspects of implementation, including, but not limited to, capacity building of laboratories on the global scale. Similar steps will need to follow the identification of plastic indicators as well.

Unlike the Stockholm Convention, the UNEA 5 resolution will not ban plastic production, but addresses the objective to end the plastic pollution problems. This will involve priorities and solutions that might differ between regions and countries/economies. Regionally identified problems, such as ALDFG in the Arctic, should still be addressed as a priority there. Ideally, actions and monitoring initiatives on national or regional scales should be used nationally and regionally, but also feed into an overall global framework. Creating these structures will be another future step to take.

The large regional and national variety in the field of plastic pollution needs to be considered, including issues of mismanagement of waste and attempts to reduce plastic use or introduce source separation. This will likely also involve long-term behavioural changes in society, related to greater awareness of the plastic pollution problem and the individual's responsibility to reduce this problem. Furthermore, possibilities of data collection have to be assessed realistically, and capacities need to be built to obtain data in a quality assured way and report it into widely accessible systems.

Finally, research into plastic pollution needs to continue, including, for example, sources and transport patterns, degradation from macro- to microplastics, transfers between environmental compartments and impacts on ecosystems and humans. The fact that many plastic materials contain potentially harmful chemicals as additives, adds to the complexity of plastic pollution and is a further field with clear research needs.

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5 Annexes

5.1 Information sources to be consulted, according to Terms of References for this study

- Regional sea conventions such as OSPAR and HELCOM
- Sustainable Development Goals (SDGs goal 12 and 14)
- The EU Marine Strategy Framework, The EU Waste Directive, The EU Packaging Directive, The EU Single Use Plastic Directive, the EU Waste Statistics Regulation, The circular economy action plan and other relevant EU-legislation and initiatives
- ECHA's microplastics proposal
- UNEP regional seas programmes
- AMAP and PAME programmes within Arctic Council
- The Basel Convention and other chemical conventions
- ICES relevant work on indicators
- Other relevant initiatives for example within OECD and EEA
- ECHA's Committee for Risk Assessment and Committee for Socio-Economic Analysis: Opinion on an Annex XV dossier proposing restrictions on intentionally-added microplastics

5.2 Frameworks including potential indicators, sorted by the DPSIR concept

Drivers	Pressures	State	Impacts	Responses
UNEP (2022): - Plastic production/ manufacturing - Product Trade - Transport - Consumption products - Extreme weather events OECD: - Environmental and resource productivity of the economy - Socio-economic context and characteristics of growth SDG targets on production and consumption of plastic products: - SDG Target 8.4: Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead. Directive (EU) 2019/904 (also Responses): - Article 4: Consumption reduction: Member States shall take the necessary measures to achieve an ambitious and sustained reduction in the consumption of the single-use plastic products - Article 5: Restrictions on placing on the market: Member States shall prohibit the placing on the market of certain single-use plastic products and of products made from oxo-degradable plastic - Article 6: Product requirements: Member States shall ensure that certain single-use plastic products that have caps and lids made of plastic may be placed on the market only if the caps and lids remain	UNEP (2022): - Raw material extraction, incl. production of monomers and polymers - Outdoor abrasions - Emissions to environment, i.e. Direct: Plastic products, additives, industrial waste incl. pellets, powders; Indirect: Abrasion of micro-plastic - Leakages/fluxes: e.g. divided into 10 sources as in the OSPAR Matrix Score approach: Fishing (incl. fishing ports); Tourism and recreational activities; Commercial shipping; Harbour operations and facilities; Land-based commerce and industry; Recreational boating (incl. marinas); Other maritime industries (e.g. offshore); Aquaculture; Waste disposal and collection; Sewage outlets and rainwater overflows SDG targets on raw material extraction: - SDG Target 6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity - SDG Target 7.2: By 2030, increase substantially the share of renewable energy in the global energy mix - SDG Target 12.2: Sustainable management and efficient use of natural resources - SDG Target 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services,	UNEP (2022): - Concentrations, characteristics, composition and trends of macro- and micro-plastic in/on marine environment: Coastline, Beach, Sea surface, Water column, Seafloor/sediment, Biota (ingestion, entanglement) - Freshwater, air and soil as indirect measures of state for the marine environment OECD: Natural asset base GESAMP (2019): Monitoring biota as an overall indicator of ecosystem contamination SDG target on marine and coastal environment: - SDG Target 14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution. SDG targets on freshwater: - SDG Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally - SDG Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes SDG target on air and humans: - SDG 12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release	UNEP (2022): Trends and changes in state (also Responses): - Ecosystem health: Biodiversity, mortality, reproduction of species, food web and habitat impacts - Ecosystem services: Climate regulation, primary productivity, recycling of nutrients, protection from severe weather events - Economic: Prevention, damage, clean-up, hazards, mitigation, lost opportunities, indirect, trade barriers/profits - Human (via environment): Health, well-being, livelihoods, food security, water security OECD (also Drivers): - Environmental dimension of quality of life SDG targets on ecosystem health: - SDG Target 12.4: By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment - SDG Target 14.5: By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information - SDG Target 15.5: Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species. SDG targets on ecosystem services:	UNEP (2022): Governance: - Policy and law: Legislation, standards, strategies, action plans, roadmaps, EPR, Circularity, waste management, monitoring programmes, removal programmes - Technology, Innovation, Research: Materials, services, alternatives, monitoring, impact, infrastructure, pathways - Sustainable finance: Public, private sector, public-private partnerships, grants and donors - Cooperation & capacity-building: MEAs, intergovernmental and regional agreements, Basel Convention Partnership on Plastic Waste, technical & financial assistance, awareness & education OECD (also Driver): Economic opportunities and policy responses SDG targets on policy and law: - SDG Target 15.5: Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species - SDG Target 12.1: Implement the 10-Year Framework of Programs on sustainable consumption and production (10YFP), all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries - SDG Target 6.b: Support and strengthen the participation of local communities in improving water and sanitation management - SDG Target 8.3: Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services - SDG Target 12.7: Promote public procurement practices that are sustainable, in accordance with national policies and priorities

attached to the containers during the products' intended use stage - Article 7: Marking requirements: Member States shall ensure that each certain single-use plastic product placed on the market bears a conspicuous, clearly legible and indelible marking on its packaging or on the product itself informing consumers of the following: (a) appropriate waste management options, and (b) the presence of plastic in the product and the resulting negative impact of littering on the environment. - Article 8: Extended producer responsibility: 1) Member States shall ensure that extended producer responsibility schemes are established for all certain single-use plastic products, which are placed on the market, in accordance with Directive 2008/98/EC. 2) Member States shall ensure that the producers of certain single-use plastic products cover the costs pursuant to the extended producer responsibility provisions in Directives 2008/98/EC and 94/62/EC. 3) Member States shall ensure that the producers of certain single-use plastic products cover at least the following costs: (a) the costs of the awareness raising measures, (b) the costs of cleaning up litter resulting from those products and the subsequent transport and treatment of that litter, (c) the costs of data gathering and reporting in accordance with Directive 2008/98/EC. - Article 12: Specifications and guidelines on single-use plastic products: The Commission shall publish guidelines, in consultation with Member States, of what is to be considered a single-use plastic product - Article 13: Information systems and reporting on data on certain single-use plastic products: e.g. to demonstrate the consumption reduction, the attainment of the	in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements Directive (EU) 2019/904: - Article 11: Coordination of measures: The measures that Member States take shall comply with Union food law to ensure that food hygiene and food safety are not compromized, by encouraging the use of sustainable alternatives to single-use plastic where possible for materials intended to come into contact with food ECHA (2020a and 2020b) (also State): Regarding restrictions on intentionally added micro-plastic: - The implementation of the proposed restrictions can be monitored via calculating emissions and, potentially, through monitoring studies of certain types of relevant micro- plastic in wastewater and sludge (e.g. microbeads, which tend to be fairly large)	to air, water and soil in order to minimize their adverse impacts on human health and the environment SDG target on soil: - SDG Target 15.5: Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species SDG target on biota: - SDG Target 15.5: Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species EC (2020) (also Drivers and Pressures): The Commission will address the presence of micro-plastic in the environment by: - Restricting intentionally added micro-plastic and tackling pellets taking into account the opinion of the European Chemicals Agency - Developing labelling, standardisation, certification and regulatory measures on unintentional release of micro-plastic, including measures to increase the capture of micro-plastic at all relevant stages of products' lifecycle - Further developing and harmonising methods for measuring unintentionally released micro-plastic, especially from tyres and textiles, and delivering harmonized data on micr-plastic concentrations in seawater - Closing the gaps on scientific knowledge related to the risk and occurrence of micro-plastic in the environment, drinking water and foods AMAP (2021a): Research recommendations for micro-plastic monitoring in Arctic fish:	- SDG Target 14.2: By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans - SDG Target 6.5: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate - SDG Target 15.2: By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally SDG targets on economics: - SDG Target 8.9: By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products - SDG Target 8.2: Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors - SDG Target 9.4: By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities SDG targets on humans: - SDG Target 8.2: Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors - SDG Target 3.9: By 2030, substantially reduce the number of deaths	- SDG Target 13.2: Integrate climate change measures into national policies, strategies and planning - SDG Target 15.9: By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts - SDG Target 17.14: Enhance policy coherence for sustainable development SDG targets on technology, innovation and research: - SDG Target 8.2: Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors - SDG Target 9.4: By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities - SDG Target 17.7: Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms, including on concessional and preferential terms, as mutually agreed - SDG Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally SDG targets on sustainable finance: - SDG Target 15.a: Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems - SDG Target 12.c: Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their

separate collection targets, fishing gear containing plastic placed on the market and on waste fishing gear collected, on recycled content in beverage bottles, the post-consumption waste of certain single-use plastic products. The data and information reported by Member States shall be accompanied by a quality check report, which will be reviewed by the Commission EC (2020) (also Responses): The Commission will address emerging sustainability challenges by developing a policy framework on: - Sourcing, labelling and use of bio-based plastic, based on assessing where the use of bio-based feedstock results in genuine environmental benefits, going beyond reduction in using fossil resources - Use of biodegradable or compostable plastic, based on an assessment of the applications where such use can be beneficial to the environment, and of the criteria for such applications. It will aim to ensure that labelling a product as 'biodegradable' or 'compostable' does not mislead consumers to dispose of it in a way that causes plastic littering or pollution due to unsuitable environmental conditions or insufficient time for degradation ECHA (2020a and 2020b): Regarding restrictions on intentionally added micro-plastic: - Transition periods and derogations for certain sectors have been proposed with the aim to minimize costs to society, without unnecessary delay in emissions reduction. In this manner industry will have sufficient time to develop and transition to suitable alternatives, including biodegradable polymers where this is appropriate - Instructions for use and disposal requirements have been proposed		- Development of methods to quantify micro-plastic in muscle and liver of fish - Development of methods to quantify nano-plastics in fish tissues - Correlation of chemical contaminant data with micro-plastic exposure AMAP (2021a): Research recommendations for litter and micro-plastic monitoring in Arctic breeding seabirds: - Black Guillemot stomachs for all litter ≥ 1 mm - Parental transfer of plastic to chicks in species known to ingest plastic pollution - Non-lethal sampling of Dovekie gular pouches delivered to chicks - Northern Fulmar eggs for plastic pollution links to contaminants - Common Eider eggs for plastic pollution links to contaminants - Ingested plastic particles < 1 mm in species vulnerable to ingestion of these small particles AMAP (2021a): - Given the current evidence, including the low presence, if any, of plastics in digestive tracts, mammals are not a useful indicator of the physical occurrence of plastics in the environment AMAP (2021a): - To compare numeric values on plastic contamination between studies and to relate laboratory exposure studies with quantitative field studies, the smallest particle and largest particle sizes measured, mean and median sizes, and ideally, additional size distribution indicators need to be provided EEA (2022): - Overall status of the coast and marine waters - Status of offshore areas - Status of coastal areas	and illnesses from hazardous chemicals and air, water and soil pollution and contamination ECHA (2020a and 2020b): - A restriction under REACH should minimize releases of intentionally added micro-plastic to the environment, as per PBT/vPvB substances, in order to minimize the likelihood of adverse effects arising as a consequence of increasing exposure concentrations if the use of intentionally added micro-plastic were to be continued - Minimization of release would also minimize the potential for cumulative effects arising from the presence of both primary (intentionally added) and secondary micro-plastic in the environment	development in a manner that protects the poor and the affected communities - SDG Target 9.a: Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States SDG targets on cooperation and capacity building: - SDG Target 6.a: By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies - SDG Target 12.a: Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production - SDG Target 12.8: By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature - SDG Target 17.17: Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships

for uses where risks can be minimized by appropriate conditions of use and disposal. This provision will also enable information exchange along the supply chain - Reporting requirements have been proposed to improve the evidence base on the remaining uses of micro-plastic. This is considered a cost-effective way to enable the Commission and Member States to consider if and to what extent additional action could be needed in 5-10 years - Using existing analytical methods, to establish if micro-plastic are present in mixtures, will avoid unnecessary testing costs. Use of these methods can ensure that only non-micro- plastic polymers are used in products that inevitably lead to releases to the environment - The restriction is designed so that enforcement authorities can set up efficient supervision mechanisms to monitor compliance with the proposed restriction and is practically implementable for companies - It is possible to determine if a product includes polymer-containing particles of the relevant dimensions. For the cases where the particle is mainly non-polymer, there is also a need to determine the amount of polymer present in the particle. Applied methods for determining the amount of polymer will need to be decided on a case-by-case basis, but that suitable methods are available ECHA (2020a and 2020b): Regarding restrictions on intentionally added micro-plastic: The following sectors have specified transitional arrangements: - Cosmetic products, Controlled-release fertilisers, Microbeads contained in detergents, Fragrance encapsulates, Other micro-plastic contained in detergents, waxes, polishes and air care products,		- Abundance and trends of beach litter - Abundance of PPSI litter on beaches		

Capsule suspension plant protection products and biocides, Medical devices, Polymeric infill material - For uses derogated from the restriction on use, the proposed reporting requirement will allow information on them to be gathered and, where necessary, future additions to the restriction could be considered. For imported mixtures, the compliance control can be accomplished by border authorities and notifications of any violation of the restriction can be reported in the RAPEX system - It is recommended that the restriction is reviewed five years after entry into force to see how the market has adapted to the restriction, how well biodegradable polymers perform for the relevant uses and what additional information is available on the impacts of micro-plastic on the environment and human health. EEA (2022): - Plastic packaging production - Decoupling of plastic packaging waste generation from GDP				

- Industrial pellets (raw materials) on coastlines and in seabirds - Loss of containers at sea	SDG targets on emissions to environment: - SDG Target 12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment - Riverine inputs - Point source inputs - Airborne deposition			- Public clean-ups - Fishing for litter - Retrieval of lost fishing gear
Directive (EU) 2019/904: - Article 9: Separate collection: Member States shall take the necessary measures to ensure the separate collection for recycling - Article 10: Awareness raising measures: Member States shall take measures to inform consumers and to incentivise responsible consumer behaviour, in order to reduce litter from certain products, and shall take measures to inform consumers of certain single-use plastic products and users of fishing gear containing plastic about the following: (a) the availability of re-usable alternatives, re-use systems and waste management options as well as best practices in sound waste management carried out in accordance with Directive 2008/98/EC; (b) the impact of littering and other inappropriate waste disposal of those single-use plastic products and of fishing gear containing plastic on particularly the marine environment, (c) the impact of inappropriate means of waste disposal of certain single-use plastic products on the sewer network Directive 2008/98/EC:	SDG targets on waste management (also Responses): - SDG Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management - SDG Target 12.5: Substantially reduce waste generation through prevention, reduction, recycling and reuse - SDG Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally Directive 94/62/EC (also Responses): - Article 4: Prevention: Member States shall ensure that, in addition to the measures taken in accordance with Article 9, other preventive measures are implemented in order to prevent generation of packaging waste and to minimize the environmental impact of packaging. The	Directive 2008/98/EC: - Article 17: Control of hazardous waste: Member States shall take the necessary action to ensure that the production, collection and transportation of hazardous waste, as well as its storage and treatment, are carried out in conditions providing protection for the environment and human health - Article 18: Ban on the mixing of hazardous waste: Member States shall take the necessary measures to ensure that hazardous waste is not mixed, either with other categories of hazardous waste or with other waste, substances or materials Regulation (EC) No 2150/2002: - Article 3: Collection of data: Member States shall, whilst complying with conditions as to quality and accuracy, acquire the data necessary for the specification of the characteristics listed in Annexes I and II by means either of: surveys; administrative or other sources, such as the reporting obligations under Community legislation on waste management; statistical estimation procedures on the basis of samples or waste related estimators; a combination of these means	Directive 2008/98/EC: - Article 13: Protection of human health and the environment: Member States shall take the necessary measures to ensure that waste management is carried out without endangering human health, without harming the environment and, in particular: (a) without risk to water, air, soil, plants or animals, (b) without causing a nuisance through noise or odours, (c) without adversely affecting the countryside or places of special interest	Amounts for: - Incineration - Recycling Directive 94/62/EC: - Article 5: Reuse: Member States shall take measures to increase the share of reusable packaging placed on the market and of systems to reuse packaging in an environmentally sound manner, and without compromising food hygiene or the safety of consumers - Article 8: Marking and identification system: The Council shall facilitate collection, reuse and recovery including recycling, packaging. Furthermore packaging shall bear the appropriate marking either on the packaging itself or on the label - Article 8a: Specific measures for biodegradable and compostable plastic carrier bags - Article 10: Standardization: The Commission shall promote criteria and methodologies for life-cycle analysis of packaging, methods for measuring and verifying the presence of heavy metals and other dangerous substances in the packaging and their release into the environment from packaging and packaging waste, criteria for a minimum content of recycled material in packaging for appropriate types of packaging, criteria for recycling methods, criteria for composting methods and produced compost, criteria for the marking of packaging - Article 11: Concentration levels of heavy metals present in packaging: Member States shall

- Article 4: Waste hierarchy: The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy: (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery, e.g. energy recovery; (e) disposal - Article 7: List of waste shall include hazardous waste and shall take into account the origin and composition of the waste and, where necessary, the limit values of concentration of hazardous substances - Article 8: Extended producer responsibility: In order to strengthen the re-use and the prevention, recycling and other recovery of waste, Member States may take legislative or non- legislative measures to ensure that any natural or legal person who professionally develops, manufactures, processes, treats, sells or imports products (producer of the product) has extended producer responsibility - Article 14: Costs: In accordance with the polluter-pays principle, the costs of waste management, including for the necessary infrastructure and its operation, shall be borne by the original waste producer or by the current or previous waste holders - Article 15: Responsibility for waste management: Member States shall take the necessary measures to ensure that any original waste producer or other holder carries out the treatment of waste himself or has the treatment handled by a dealer or an establishment or undertaking which carries out waste treatment operations or arranged by a private or public waste collector - Article 16: Principles of self-sufficiency and proximity: Member States shall take appropriate measures to establish an integrated and adequate network of waste	Commission shall help to promote prevention by encouraging the development of suitable European standards, which shall aim to minimize the environmental impact of packaging - Article 6: Recovery and recycling: Member States shall take the necessary measures to attain targets on recovery and recycling of packaging waste - Article 6a: Rules on the calculation of the attainment of the targets: Member States shall calculate the weight of packaging waste generated and recycled in a given calendar year. The weight of packaging waste recycled shall be calculated as the weight of packaging that has become waste. Member States shall establish an effective system of quality control and traceability of the packaging waste - Article 7: Return, collection and recovery systems: Member States shall take the necessary measures to ensure that systems are set up to provide for the return and/or collection of used packaging and/or packaging waste from the consumer, other final user, or from the waste stream in order to channel it to the most appropriate waste management alternatives; The reuse or recovery including recycling of the packaging and/or packaging waste collected. Member States shall take measures to promote high quality recycling of packaging waste and to meet the necessary quality standards for the relevant recycling sectors. EEA (2022): - PPSI waste generated per capita - Share of mismanaged PPSI waste	- Article 5: Import and export of waste: The Commission shall draw up a programme for pilot studies on the import and export of waste to be carried out by Member States. The pilot studies shall aim at developing a methodology to obtain regular data which shall be governed by the principles of Community statistics - Annex I (generation of waste), and Annex II (recovery and disposal of waste) comprise covered waste categories, report on the coverage and quality of statistics, and transmission of results to Eurostat		ensure that the sum of concentration levels of lead, cadmium, mercury and hexavalent chromium present in packaging or packaging components shall not exceed certain threshold values - Article 12: Information systems and reporting: Member States shall take the necessary measures to ensure that databases on packaging and packaging waste are established - Article 13: Information for users of packaging: Member States shall take measures to ensure that users of packaging, including in particular consumers, obtain the necessary information about: the return, collection and recovery systems available to them; their role in contributing to reuse, recovery and recycling of packaging and packaging waste, the meaning of markings on packaging existing on the market, the appropriate elements of the management plans for packaging and packaging waste. Member States shall also promote consumer information and awareness campaigns - Article 20a: Reporting on plastic carrier bags: By 27 November 2021, the Commission shall present a report to the European Parliament and to the Council, assessing the effectiveness of measures in Article 4(1a) at Union level, in combating littering, changing consumer behaviour and promoting waste prevention Directive 2008/98/EC (also Drivers): - Article 6: End-of-waste status: Member States shall take appropriate measures to ensure that waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste - Article 9: Prevention of waste: Member States shall monitor and assess the implementation of the waste prevention measures - Article 10: Recovery: Member States shall take the necessary measures to ensure that waste undergoes preparing for re-use, recycling or other recovery operations - Article 11: Preparing for re-use and recycling: Member States shall take measures to promote preparing for re-use activities - Article 12: Disposal: Member States shall ensure that, where recovery is not undertaken, waste undergoes safe disposal operations - Article 28: Waste management plans: Member States shall ensure that their competent

disposal installations and of installations for the recovery of mixed municipal waste collected from private households, including where such collection also covers such waste from other producers, taking into account best available techniques EC (2020): To increase uptake of recycled plastic and contribute to the more sustainable use of plastic, the Commission will propose mandatory requirements for recycled content and waste reduction measures for key products such as packaging, construction materials and vehicles, also taking into account the activities of the Circular Plastic Alliance BC (2019) (also Responses): General obligations on: - Import of hazardous wastes or other wastes for disposal - Prohibition or permission of export of hazardous wastes and other wastes - Reduction of generation of hazardous wastes and other wastes - Ensure the availability of adequate disposal facilities - Ensure to prevent pollution due to hazardous wastes and other wastes arising from waste management - Ensure that the transboundary movement of hazardous wastes and other wastes is reduced to the minimum - Not allow the export of hazardous wastes or other wastes to certain states - Requirements to information about a proposed transboundary movement of hazardous wastes and other wastes - Prevent the import of hazardous wastes and other wastes if the	- Mismanaged PPSI waste per capita - Total mismanaged PPSI waste generated - Pressure mismanaged PPSI waste at the coast - Annual riverine floating litter discharged into the sea			authorities establish one or more waste management plans - Article 29: Waste prevention programmes: Member States shall establish waste prevention programmes setting out at least the waste prevention measures as laid down in Article 9(1) in accordance with Articles 1 and 4 - Article 30: Evaluation and review of plans and programmes: Member States shall ensure that the waste management plans and waste prevention programmes are evaluated at least every sixth year and revised as appropriate - Article 31: Public participation: Member States shall ensure that relevant stakeholders and authorities and the general public have the opportunity to participate in the elaboration of the waste management plans and waste prevention programmes, and have access to them once elaborated - Article 32-37: Cooperation, information to be submitted to the Commission, inspections, record keeping, enforcement and penalties, reporting

wastes will not be managed in an environmentally sound manner - Co-operate in activities with other Parties and interested organizations - Illegal traffic in hazardous wastes or other wastes is criminal - Taking legal, administrative and other measures to implement and enforce the provisions of this Convention - Packaging, labelling, transport and documentation of movement of hazardous wastes and other wastes that are to be the subject of a transboundary movement - Management of hazardous wastes and other wastes in an environmentally sound manner				

5.3 Currently used indicators, sorted by the DPSIR concept

Drivers	Pressures	State	Impacts	Responses
OECD (Green Growth indicators): Environmental and resource productivity of the economy: - Production-based CO2 productivity - Demand-based CO2 productivity - Energy productivity - Energy intensity by sector - Share of renewable energy sources - Demand-based material productivity - Production-based (domestic) material productivity - Waste generation intensity and recovery ratios - Nutrient flows and balances (N, P) - Water productivity - Environmentally adjusted multifactor productivity OECD (Green Growth indicators): Socio-economic context and characteristics of growth: - Economic growth, productivity and competitiveness (economic growth and structure, productivity and trade, inflation and commodity prices) - Labour market, education and income (labour markets, socio-demographic patterns) OECD (Socio-Economic indicators): - GDP And Population (gross domestic product, population growth and density) - Consumption (private consumption, government consumption) - Energy (energy intensities, energy mix) - Expenditure (pollution abatement and control expenditure, official development assistance) OECD (Circular Economy indicators) (also State): - Waste (total waste, intensities per capita or GDP, municipal waste, intensities per capita, municipal waste by treatment operation: composting, incineration with/without energy recovery, landfill, other disposal, recycling, other recovery)	OECD (Environmental indicators) (also State): - Climate Change (CO2 emission intensities, greenhouse gas concentrations) - Ozone Layer Depletion (ozone depleting substances) - Air Quality (air emission intensities, urban air quality) - Waste (waste generation, waste recycling) - Water Quality (river quality, waste water treatment) - Water Resources (intensity of use of water resources, public water supply and price) - Forest Resources (intensity of use of forest resources, forest and wooded land) SDG (indicator on emissions to environment): - SDG Indicator 13.2.2: Total greenhouse gas emissions per year SDG (indicator on waste management): - SDG Indicator 13.2.2: Total greenhouse gas emissions per year SDG (indicator on raw material extraction) (also Responses): - SDG Indicator 12.5.1: National recycling rate, tons of material recycled	Biota; - RSCAP (common indicator)[1)] Beach litter: - RSCAP (common indicator)[2)] Seafloor litter: - RSCAP (common indicator)[3)] Micro-plastic: - RSCAP (recommended common indicator)[4)] - OSPAR and HELCOM is currently working to develop new indicators, including micro-plastic in sediments . Water column/floating litter: - RSCAP (common indicator)[5)] Monitoring (ECOQ for ingestion of litter in indicator species suitable for monitoring, i.e. sea turtles): - RSCAP (indicators under consideration or development at the regional level) Ingestion of litter in other biota (e.g. fish and turtles): -RSCAP (indicators under consideration or development at the regional level) OECD (Green Growth indicators): Natural asset base: - Natural resource stocks (index of natural resources) - Renewable stocks (freshwater, forest and fish resources) - Non-renewable stocks (mineral resources) - Biodiversity and ecosystems (land, soil and wildlife resources) SDG (indicator on marine and coastal environment):	Biota; - RSCAP (common indicator)[1)] OECD (Green Growth indicators) (also Driver): Environmental dimension of quality of life: - Environmental health and risks (environmentally induced health problems and related costs, exposure to natural or industrial risks and related economic losses) - Environmental services and amenities (access to sewage treatment and drinking water) SDG (indicators on ecosystem health): - SDG Indicator 15.1.2: Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type - SDG Indicator 15.4.1: Coverage by protected areas of important sites for mountain biodiversity	Proof of action implementation: - RSCAP (common indicator)[6)] OECD (Green Growth indicators) (also Driver): Economic opportunities and policy responses: - Technology and innovation (research and development expenditure of importance to green growth, patents of importance to green growth, environment-related innovation in all sectors) - Environmental goods and services (production of environmental goods and services (EGS)) - International financial flows (international financial flows of importance to green growth) - Prices and transfers (environmentally related taxation and subsidies, energy pricing, water pricing and cost recovery (tbd)) - Regulations and management approaches (indicators to be developed) - Training and skill development (indicators to be developed) New Plastic Economy Global Commitment[7)] (indicators for tracking progress): - Elimination of problematic or unnecessary plastic packaging (redesign, innovation, and new delivery models) - Moving from single-use to reuse models - Reusable, recyclable or compostable by design - Reuse, recycling or composting in practice - Decoupling from the consumption of finite resources - Transparency (proportion of signatories reporting) SDG (indicator on policy and law): - SDG Indicator 15.2.1: Progress towards sustainable forest management

- Material use (domestic material consumption: biomass, fossil energy materials/carriers, non-metallic minerals, metals) - Domestic material consumption - Material productivity - Material footprint per capita EU (2020) (Circular economy indicators[8]) (also Responses): - Production and consumption (EU self-sufficiency for raw materials, generation of municipal waste per capita, generation of waste excluding major mineral wastes per GDP unit, generation of waste excluding major mineral wastes per domestic material consumption) - Waste Management (recycling rate of municipal waste, recycling rate of all waste excluding major mineral waste, recycling rate of packaging waste by type of packaging, recycling rate of e-waste, recycling of biowaste, recovery rate of construction and demolition waste) - Secondary raw materials (contribution of recycled materials to raw materials demand - end-of-life recycling input rates (EOL-RIR), circular material use rate, trade in recyclable raw materials) - Competitiveness and innovation (private investments, jobs and gross value added related to circular economy sectors, patents related to recycling and secondary raw materials)		– 14.1.1b: Index of plastic debris density SDG (indicator on waste generation and management): - 12.4.2 (a) Hazardous waste generated per capita; and (b) Proportion of hazardous waste treated, by type of treatment		Directive 2008/98/EC: - Article 9: Prevention of waste: Member States shall monitor and assess the implementation of the waste prevention measures using qualitative or quantitative indicators and targets, notably on the quantity of waste that is generated. Further The Commission shall adopt implementing acts to establish indicators to measure the overall progress in the implementation of waste prevention measures - Article 28: Waste management plans shall contain appropriate qualitative or quantitative indicators and targets, including on the quantity of generated waste and its treatment and on municipal waste that is disposed of or subject to energy recovery - Article 29: Waste prevention programmes with development of effective and meaningful indicators of the environmental pressures associated with the generation of waste aimed at contributing to the prevention of waste generation at all levels, from product comparisons at Community level through action by local authorities to national measures

1) RSCAP: Regional Plan on Marine Litter Management in the Mediterranean; PAME- Regional Action Plan on Marine Litter in the Arctic; OSPAR - Regional Action Plan for Prevention and Management of Marine Litter in the North-East Atlantic; Black Sea Marine Litter Regional Action Plan; - Regional Action Plan for Marine Litter in the Baltic Sea; Commission for the Conservation of Antarctic Marine Living Resources.

2) RSCAP: Regional Plan on Marine Litter Management in the Mediterranean; PERSGA - Regional Action Plan for the sustainable Management of Marine Litter in the Red Sea and Gulf of Aden; PAME- Regional Action Plan on Marine Litter in the Arctic; OSPAR - Regional Action Plan for Prevention and Management of Marine Litter in the North-East Atlantic; NOWPAP Regional Action Plan on Marine Litter; Western Ocean Regional Action Plan on Marine Litter (WIO-RAPMaLi); Regional Action Plan on Marine litter Management for the Wider Caribbean Region 2014; Black Sea Marine Litter Regional Action Plan; HELCOM Regional Action Plan on Marine Litter - Regional Action Plan for Marine Litter in the Baltic Sea; Commission for the Conservation of Antarctic Marine Living Resources.

3) RSCAP: Regional Plan on Marine Litter Management in the Mediterranean; PERGSA - Regional Action Plan for the sustainable Management of Marine Litter in the Red Sea and Gulf of Aden; OSPAR - Regional Action Plan for Prevention and Management of Marine Litter in the North-East Atlantic; NOWPAP Regional Action Plan on Marine Litter; Black Sea Marine Litter Regional Action Plan. HELCOM.

4) RSCAP: Regional Plan on Marine Litter Management in the Mediterranean; PAME/AMAP - Regional Action Plan on Marine Litter in the Arctic; OSPAR - Regional Action Plan for Prevention and Management of Marine Litter in the North-East Atlantic; Western Ocean Regional Action Plan on Marine Litter (WIO-RAPMaLi); Black Sea Marine Litter Regional Action Plan; HELCOM .

5) RSCAP: Regional Plan on Marine Litter Management in the Mediterranean; PERSGA - Regional Action Plan for the sustainable Management of Marine Litter in the Red Sea and Gulf of Aden; Black Sea Marine Litter Regional Action Plan; HELCOM; PAME/AMAP.

6) RSCP: Regional Plan on Marine Litter Management in the Mediterranean; SPREP - Pacific Regional Action Plan Marine Litter; PERSGA - Regional Action Plan for the sustainable Management of Marine Litter in the Red Sea and Gulf of Aden; PAME - Regional Action Plan on Marine Litter in the Arctic; Western Ocean Regional Action Plan on Marine Litter (WIO-RAPMaLi); Black

Sea Marine Litter Regional Action Plan; ASEAN Framework of Action on Marine Debris; HELCOM Regional Action Plan on Marine Litter - Regional Action Plan for Marine Litter in the Baltic Sea; Abidjan Convention; TEHERAN Convention - Caspian Sea.

[7] 2019 Progress Report at: https://emf.thirdlight.com/link/d81jyzj5q3li-ico7uz/@/preview/1?o

[8] https://ec.europa.eu/eurostat/web/circular-economy

5.4 Macrolitter indicators and recommendations for marine litter monitoring in Europe (incl. Arctic)

<table>
<tr><th>Framework</th><th>Geo-graphical scale</th><th>Beach Litter</th><th>Seabed/Sediments</th><th>Floating Litter and water column</th><th>Plastic ingestion by biota</th><th>Entanglement and other adverse effects on biota</th></tr>
<tr><td>EU MSFD</td><td>EU</td><td colspan="3">D10C1 Primary: The composition, amount and spatial distribution of litter (excluding micro-litter) on the coastline, in the surface layer of the water column, and on the seabed, are at levels that do not cause harm to the coastal and marine environment.[1)]
Complementary assessment information on specific litter categories for artificially polymers, single use plastic (SUP) and fishing gear</td><td>D10C3 Secondary: The amount of litter and micro-litter ingested by marine animals is at a level that does not adversely affect the health of the species concerned.1)

Regionally agreed indicator species:
- Fulmar (North-East Atlantic)
- Loggerhead turtle (Mediterranean Sea)</td><td>D10C4 Secondary: The number of individuals of each species which are adversely affected due to litter, such as by entanglement, other types of injury or mortality, or health effects.1)

There are no regionally agreed indicator species yet available for assessment</td></tr>
<tr><td>OSPAR</td><td>North East Atlantic</td><td>Common indicator: Beach litter (all visible litter on the beach surface).
Corresponding to the MSFD indicator 10.1.1: The composition, amount and spatial distribution of litter (excluding micro-litter) on the coastline.
OSPAR CEMP protocol (2021) ©</td><td>Common indicator: Litter on the seabed.
Corresponding to the MSFD indicator 10.1.2: The composition, amount and spatial distribution of litter (excluding micro-litter) on the seabed.
Using e.g. IBT surveys

OSPAR CEMP protocol (2017) ©</td><td>n.p.</td><td>Plastic ingested by seabirds (mostly micro- and mesoplastic: < 1 mm : “Ecological indicator” for trends in marine litter (EcoQO 3.3), and “Impact on biota” indicator corresponding to the MSFD indicator 10.2.1: litter ingested by marine organisms and other impacts of litter on biota.

Ingestion of litter by sea turtles as a candidate indicator for impact of marine litter on biota.

Fulmars (>1mm) ©; shearwaters (>1mm); sea turtles (>1mm)

OSPAR CEMP protocols (2019, 2020)</td><td>n.p.</td></tr>
</table>

HELCOM	Baltic Sea	Core indicator: characteristics and abundance/volume (>5mm). Monitoring units: number of litter items per 100m beach segment. Guidelines: HELCOM (2016a; 2017a). OSPAR, UNEP/MARLIN protocols ©	Pre-core indicator: Macro-litter characteristics and abundance/volume using e,g,BIT survey protocol	n.p.	n.p.	n.p.
Barcelona Convention	Mediterranean Sea	Common indicator 22. Trends in the amount of litter washed ashore and/or deposited on coastlines, i.e. beach litter.	Common indicator 23. Trends in the amount of litter on the seabed.	Common indicator 23: Trends in the amount of litter in the water column incl. MPs and floating litter	Candidate common indicator 24: Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds and marine turtles.	Candidate common indicator 24: Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds and marine turtles. Entanglement of sea turtles
Bucharest Convention (BSC)	Black Sea	n.a. UNEP protocol ©	EcoQO 4. Common indicator: Trends in the amount of litter deposited on the seabed.	EcoQO 4. Common indicator: Trends in the amount of litter in the water column incl. MPs and floating litter	EcoQO 4. Common indicator: Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds, fish.	EcoQO 4. Common indicator: Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds, fish.
AMAP	Arctic region	Recommended primary monitoring indicators: Accumulation surveys of litter at reference sites of 100 m segments on shorelines following OSPAR or NOAA guidelines	n.p.	n.p.	Primary indicators: Northern Fulmar (>1mm) ©	n.p.

© Recommended as core/primary indicators
n.p.: Not prioritized as core/primary recommended monitoring indicators
n.a.: Not available

[1)] For the MSFD D10C1, D10C2, D10C3 and D10C4 criteria Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional or sub-regional specificities. Threshold values are under development

5.5 Microlitter indicators and recommendations for marine litter monitoring in Europe (incl. Arctic)

Framework	Geographical scale	Beach Litter	Seabed/Sediments	Floating Litter and water column	Plastic ingestion by biota	Entanglement and other adverse effects on biota
EU MSFD	EU	D10C2 Primary: The composition, amount and spatial distribution of micro-litter on the coastline, in the surface layer of the water column, and in seabed sediment, are at levels that do not cause harm to the coastal and marine environment.1) The GES Decision sets out 'artificial polymer materials' and 'other' as assessment elements for micro-litter (particles <5 mm).			D10C3 Secondary: The amount of micro-litter ingested by marine animals is at a level that does not adversely affect the health of the species concerned.1) Litter and micro-litter should be assessed, where possible, in representative species from the following groups: birds, reptiles, fish, or invertebrates.	n.p.
OSPAR	North East Atlantic	n.p.		n.p..	Plastic ingested by fulmar: "Ecological indicator" for trends in marine litter (EcoQO 3.3), and "Impact on biota" indicator corresponding to the MSFD indicator 10.2.1.	
HELCOM	Baltic Sea	n.p.			n.p.	n.p.
Barcelona Convention	Mediterranean Sea	n.a.	n.a. MEDIT survey protocol; video recordings?	Common indicator 23: Trends in the amount of litter in the water column incl. MPs and on the seabed.		
Bucharest Convention (BSC)	Black Sea	n.a.	EcoQO 4. Common indicator: Trends in the amount of litter deposited on the seabed	EcoQO 4. Common indicator: Trends in the amount of litter in the water column incl. MPs and floating litter		
AMAP	Arctic region	n.p.	Recommended for aquatic sediments, size ranges 300 µm–1 mm and 1-5 mm ©	Recommended with 300 µm cut-off (or lower) in coastal waters; with 100 µm, 300 µm and 1000 µm in offshore waters ©		

© Recommended as core/primary indicators

n.p.: Not prioritized as core/primary or candidate/secondary recommended monitoring indicators
n.a.: Not available
1) For the MSFD D10C1, D10C2, D10C3 and D10C4 criteria Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional or sub-regional specificities. Threshold values are under development.

5.6 Plastic use, waste generation and leakage

Overall plastic use has increased steadily since 1950 with the majority (ca. 46%) of plastic use in 2019 in OECD countries in America and Europe.

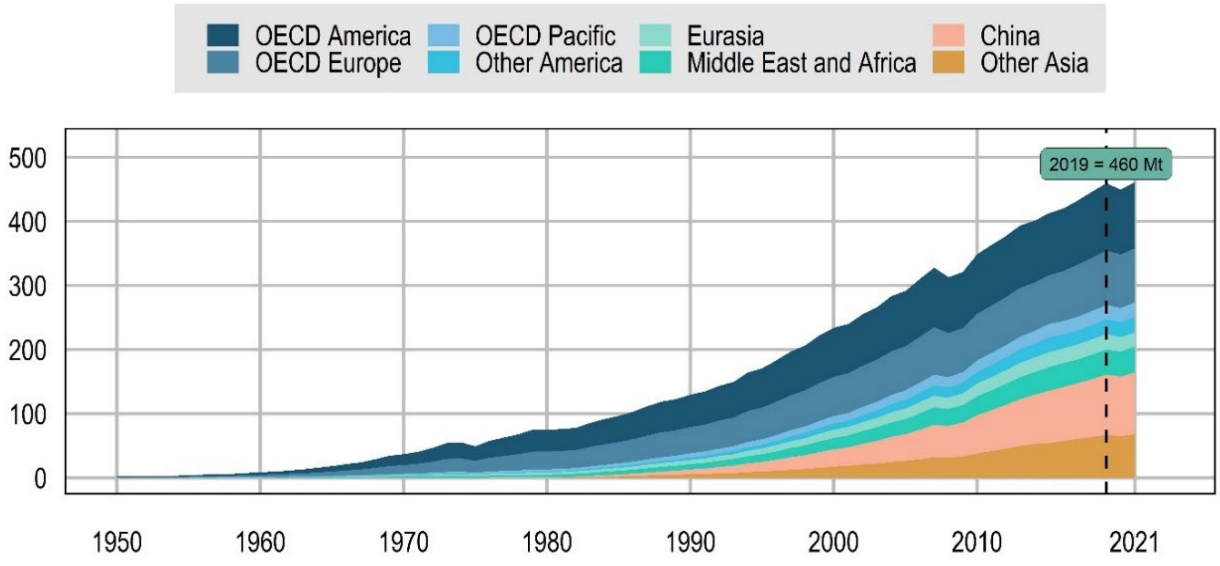

Figure A1: Global plastics use has quadrupled in 30 years, mainly driven by emerging economies (OECD, 2022b).

Globally, 460 million metric tonnes (Mt) of plastic were used in 2019, with the majority used as packaging or as part of construction.

Table A1: Plastic use by application in 2019 (OECD, 2022a).

Plastic application	% of total use	Amount [Mt]
Packaging	31%	142.6
Construction	17%	76.9
Other	15%	67.6
Transportation	12%	54.4
Consumer products	10%	46.7
Textiles	10%	43.9
Electronics and machinery	4%	20.0
Tyres	2%	7.7
TOTAL	100%	459.7

The most used polymers are polypropylene (PP), synthetic fibres (mainly made from PP, PET or PA, and polyethylene (HDPE, LDPE and LLDPE).

Table A2: Plastic use by polymer type in 2019 (OECD, 2022a).

Polymer type	% of total	Amount [Mt]
Other	18%	81.0
Polypropylene (PP)	16%	72.8
Synthetic fibres	13%	60.4
HDPE	12%	55.5
LDPE, LLDPE	12%	54.3
PVC	11%	51.4
Polyethylene tereptalate (PET)	5%	24.9
PS	5%	21.1
PUR	4%	18.0
ABS, ASA, SAN	2%	8.9
Elastomers (tyres)	2%	7.7
Bioplastics	1%	2.3
Road marking coatings	0%	0.7
Marine coatings	0%	0.5
TOTAL	100%	459.7

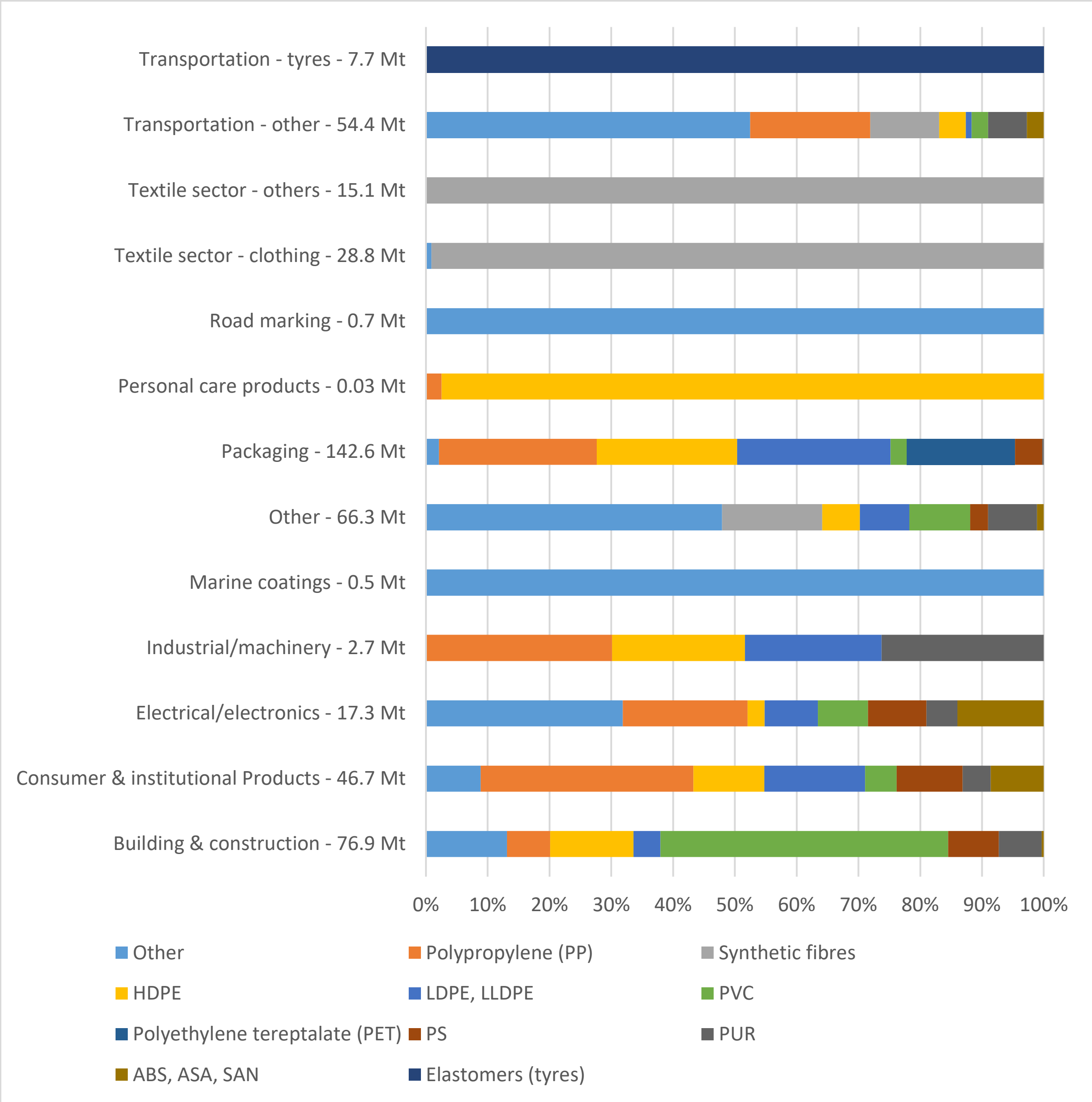

Figure A2: Detailed presentation of plastic polymers used in different application categories in 2019.

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Table A3: Plastic waste generation in million metric tonnes in 2019 split into regions and applications.

Region	Building & construction	Consumer & institutional Products	Electrical/electronics	Industrial/machinery	Marine coatings	Other	Packaging	Personal care products	Road marking	Textile sector - clothing	Textile sector - others	Transportation - other	Transportation - tyres	Total
Other Asia	1%	11%	3%	0%	0%	13%	38%	0%	0%	15%	4%	12%	2%	100%
China	1%	13%	4%	0%	0%	17%	45%	0%	0%	8%	4%	7%	1%	100%
Middle East and Africa	2%	13%	4%	0%	0%	18%	45%	0%	0%	5%	4%	7%	1%	100%
Eurasia	4%	10%	4%	0%	0%	12%	32%	0%	0%	8%	4%	22%	3%	100%
Other America	1%	14%	4%	1%	0%	19%	46%	0%	0%	4%	4%	6%	1%	100%
OECD Pacific	12%	12%	5%	0%	0%	15%	37%	0%	0%	8%	4%	7%	1%	100%
OECD Europe	11%	12%	4%	1%	0%	17%	39%	0%	0%	4%	4%	9%	1%	100%
OECD America	5%	12%	4%	1%	0%	17%	38%	0%	0%	7%	4%	11%	2%	100%

Table A4: Plastic waste generation in million metric tonnes in 2019 split into applications and polymers

Plastic application	**ABS, ASA, SAN**	**Bioplastics**	**Elastomers (tyres)**	**Fibres**	**HDPE**	**LDPE, LLDPE**	**Marine coatings**	**Other**	**PET**	**PP**	**PS**	**PUR**	**PVC**	**Road marking coatings**	**Total**
Building & construction	0.1	0.0	0.0	0.0	2.1	0.7	0.0	2.2	0.0	1.1	1.4	1.2	7.6	0.0	16.2
Consumer & institutional Products	3.7	0.1	0.0	0.0	4.9	7.0	0.0	3.6	0.0	14.7	4.6	1.9	2.2	0.0	42.6
Electrical/electronics	2.0	0.0	0.0	0.0	0.4	1.2	0.0	4.4	0.0	2.8	1.3	0.7	1.1	0.0	13.9
Industrial/machinery	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	1.3
Marine coatings	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Other	0.6	0.2	0.0	9.4	3.4	4.5	0.0	27.7	0.0	0.0	1.7	4.6	5.6	0.0	57.8
Packaging	0.0	1.3	0.0	0.0	32.2	35.3	0.0	1.6	24.8	36.3	6.2	0.4	3.8	0.0	142.0
Personal care products	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Road marking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6
Textile sector - clothing	0.0	0.2	0.0	24.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.1
Textile sector - others	0.0	0.0	0.0	13.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.6
Transportation - other	0.9	0.1	0.0	3.9	1.5	0.3	0.0	18.0	0.0	6.7	0.0	2.2	0.9	0.0	34.6
Transportation - tyres	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
Total	7.3	2.1	5.1	51.8	44.7	49.2	0.5	57.6	24.8	62.0	15.2	11.3	21.2	0.6	353.3

Table A5: Plastic leakage from different World regions for 2019 (OECD, 2022b).

World region	Macroplastic [Mt]	Microplastic [Mt]	Total [Mt]
United States	0.56	0.39	0.95
Canada	0.11	0.03	0.14
Other OECD America	0.56	0.07	0.63
OECD EU	0.55	0.28	0.83
OECD Non-EU	0.32	0.08	0.40
OECD Asia	0.09	0.08	0.17
OECD Oceania	0.03	0.02	0.05
Latin America	1.82	0.18	1.99
Other EU	0.07	0.02	0.09
Other Eurasia	1.40	0.11	1.51
Middle East & North Africa	1.41	0.18	1.59
Other Africa	3.28	0.19	3.47
China	4.38	0.49	4.88
India	1.94	0.26	2.21
Other non-OECD Asia	2.93	0.31	3.23
TOTAL	19.44	2.68	22.12

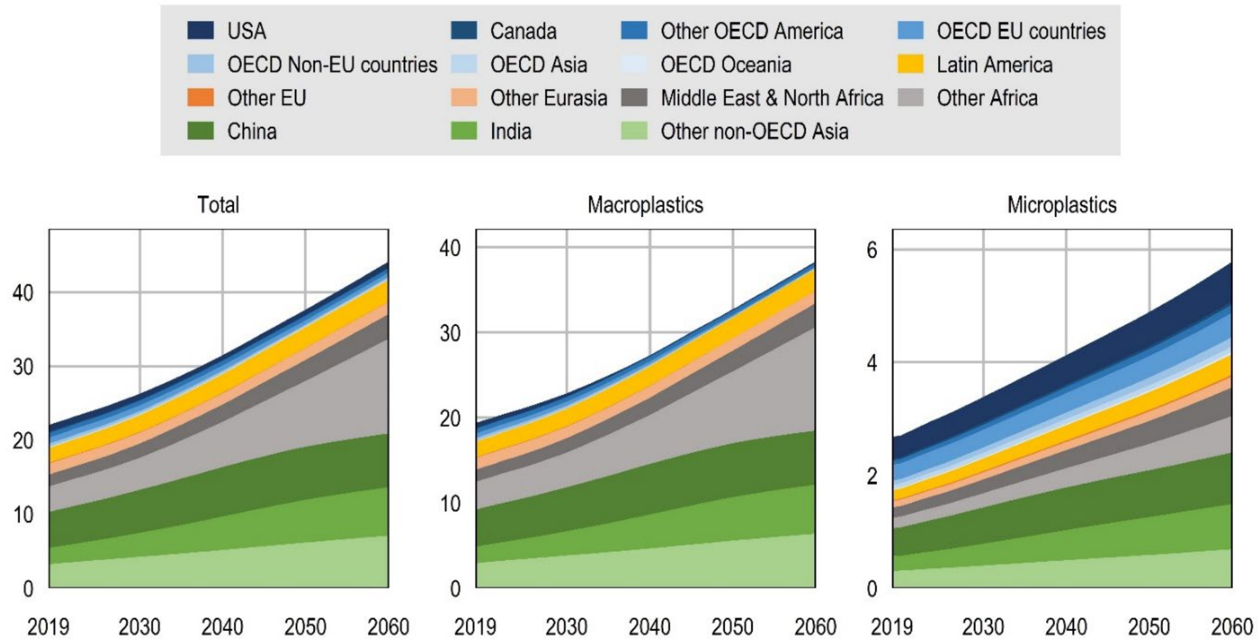

Figure A3: Estimates of plastic leakage (in million tonnes per year) from different world regions for 2019 and projected until 2060 using a business as usual scenario (OECD, 2022b).

Table A6: Leakage of macroplastics (in million tonnes per year), split into world regions and macroplastic leakage categories .

Region	Macroplastics			
	Littering	Marine activities	Mismanaged waste	Total
Other Asia	0.220	0.060	4.593	4.873
China	0.240	0.112	4.032	4.384
Middle East and Africa	0.142	0.024	4.516	4.682
Eurasia	0.055	0.006	1.403	1.464
Other America	0.070	0.010	1.737	1.817
OECD Pacific	0.028	0.016	0.078	0.121
OECD Europe	0.124	0.024	0.726	0.874
OECD America	0.192	0.011	1.023	1.226

Table A7: Leakage of microplastics (in million tonnes per year), split into world regions and microplastic leakage categories.

Region	Microplastics										
	Artificial turf	Brake dust	Marine coatings	Micro-beads	Micropla-stics dust	Primary pellets	Road mar-kings	Textile wash	Tyre abra-sion	WW sludge	Total
Other Asia	0.0042	0.0101	0.0073	0.0007	0.2661	0.0587	0.0337	0.0008	0.1464	0.0395	0.5676
China	0.0041	0.0096	0.0071	0.0020	0.1532	0.0742	0.0447	0.0040	0.1389	0.0548	0.4927
Middle East and Africa	0.0090	0.0054	0.0072	0.0002	0.1668	0.0327	0.0331	0.0003	0.0873	0.0279	0.3700
Eurasia	0.0014	0.0022	0.0036	0.0002	0.0382	0.0177	0.0154	0.0004	0.0354	0.0153	0.1298
Other America	0.0036	0.0041	0.0023	0.0001	0.0479	0.0174	0.0195	0.0002	0.0626	0.0187	0.1764
OECD Pacific	0.0010	0.0013	0.0001	0.0002	0.0083	0.0047	0.0069	0.0003	0.0192	0.0518	0.0938
OECD Europe	0.0123	0.0054	0.0077	0.0005	0.0376	0.0293	0.0274	0.0007	0.0806	0.1551	0.3566
OECD America	0.0165	0.0081	0.0129	0.0007	0.0520	0.0444	0.0398	0.0016	0.1209	0.2000	0.4967

5.7 Gap analysis for plastic loss along the plastic value chain

Location on plastics value chain	Uncertainty source	Description	Importance	Suggestions for improving estimates
Plastic production	Losses of pellets during production and handling	Only few studies have been performed quantifying the leakage of plastics from production and handling of plastics. These studies are done in developed high-income countries and data on potential leakage from production in low- and middle-income countries is lacking.	Minor importance. Production leakage is estimated to account for 0.01% of total losses. However, production leakage leads to high local concentration of plastics which could be major issue for the local environment (UN Environment, 2018)	Better monitoring of leakage. E.g. relating estimated production volume based on feedstock inputs with measurements of plastic production leaving production plant. Better strategies and procedures for reducing/avoiding leakage of plastics during production and handling. Improved monitoring of losses. In particular, for middle- and low-income countries.
Plastic use state	Leakage from abrasion	The leakage of microplastics due to abrasion of plastic and rubber products is highly uncertain. It is well known and visible that products are abraded over time. However, the actual plastic leakage and, more importantly, the fate of the leaked plastics is highly uncertain. For instance, how much goes to air and where is it transported? How much is collected as sewage systems and where does it go? How much end up in ditches and does it stay there?	Medium importance as direct leakage from abrasion is estimated to account for ca. 8% of total plastic leakage The share of rubber from tyres that is actually abraded was found to be a key parameter in estimates of global plastics leakage to the environment (Ryberg et al., 2019b).	Increased monitoring and collection of leakages and source identification to identify the potential largest leakage sources. This should be compared to known plastic uses to evaluate potential correlations between amounts used for different uses.
Plastic use state	Capture and treatment in wastewater systems	The fate of the plastics in the environment is generally poorly known. A large part of plastics are likely to be captured in sewage systems. However the actual share captured could be improved. More importantly, the subsequent fate of the plastics in the sewage is poorly known. For instance, how is the wastewater treated and what happens to the treated share, such as sludge from wastewater treatment plants.	Medium importance. Only about 2.5% of losses are estimated to be associated with sludge from wastewater treatment plants. However, a potentially large fraction of plastics lost during production, use and from littering enter the sewer system. Thus the actual amount of plastic that enters sewer system might be much larger.	Increased monitoring of wastewater in different world regions and mapping wastewater treatment and subsequent fate of wastewater sludge.

Plastic use state	Leakage from marine activities	Direct leakage of plastics from marine related activities are generally poorly accounted for in global plastic leakage models. Monitoring data on leakage is generally lacking, dated or scarce and often in combination.	Medium importance. While estimated leakage in only about 1% of total global leakage. The leaked plastics are designed to last in the marine environment. They are therefore likely to persist for longer lifetime and cause effects on the environment	Increased monitoring of leakage either by comparing inputs of marine plastic for use with outputs of marine plastic for waste management, where the difference can be seen as leaked. Most of the leakage is likely to be in middle- and low-income countries. Hence, focus should be on obtaining better data for these regions.
Plastic waste management	Littering rate and collection of littered plastics.	Littering rate is highly uncertain and studies monitoring or otherwise documenting the amount of plastic littering are lacking. In particular for middle- and low-income countries.	Medium importance as littering is estimated to account for ca. 5% of total plastic leakage	Studies focusing on measuring and quantifying littering rates in different regions and under different conditions. It is likely that drivers for littering will differ between regions. E.g. some littering might be due to bad behavior while other littering is due to lack of adequate waste management systems for correctly disposing of the plastics waste. Options and efficiency of subsequent sweeping or collection of litter should be conducted to better understand the potential fate of the littered plastic waste.
	Handling of mismanaged waste	Information on waste treatment and handling of waste that is either mismanaged or handled via informal waste sector is scarce and must be qualified.	High importance as leakages from mismanaged waste managed is the largest source of leakage with 82% of total leaked amount	Improved mapping and characterization of local and regional waste management practice to better understand the treatment share of plastics.
	Leakage from mismanaged waste	The potential leakage rate of plastics from the mismanaged waste to the environment is poorly understood. Currently, estimates are based on highly varying assumptions. The waste can be leaked via different transportation routes that are likely to be specific to the waste handling or dump site.	High importance as leakages from mismanaged waste managed is the largest source of leakage with 82% of total leaked amount. The leakage rate was also found to be the most important parameter for estimates of global leakage to the environment (Ryberg et al., 2019b).	Better monitoring of local leakage rates from e.g. dump sites are required. Potential development of models that can estimates leakage rates based on known physical characteristics about the dumpsite, such as proximity to water and the income-level of the nation/region where it is situated.

INDICATORS FOR PLASTIC POLLUTION

Plastic losses to the environment can occur at all stages of plastic production, use and disposal. Once in the environment, plastics occurs in a variety of shapes, size classes and polymers, including dynamics such as accumulation on beaches, breakdown from macro- to microplastics, and uptake in biota. Addressing plastic pollution requires reliable indicators. This study has analysed existing indicators along the plastic value chain and in the environment, including frameworks aiming at circular economy and plastic reuse and recycling. The main part of plastic losses is macroplastic, with an important source being the mismanagement of plastic waste. Thus, this would be a relevant indicator, but it is difficult to measure directly. Environmental indicators exist, which are complementary, but badly connected to upstream indicators in the plastic value chain. Furthermore, important plastic components lost in the value chain and present the environment, respectively, such as tyre abrasion and fishing gear, are not approached consistently. A lack of harmonization, e.g. in reporting units, prevents more consistency in the indicator approach. The report also includes some suggestions of potentially relevant new indicators, such as container losses, ghost nets and microplastics in wastewater.

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