Plastic Leak Project

Methodological Guidelines

Quantis + ea

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Acronyms and abbreviations

BTA	Benzotriazole
FU	Functional unit
GHG	Greenhouse gases
IUCN	International Union for Conservation of Nature
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
Mt	Million tonnes (million metric tons)
OEFCR	Organization environmental footprint category rule
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate
PBSA	Polybutylene succinate adipate
PCL	Polycaprolactone
PE	Polyethylene
PEA	Poly(ethyl acrylate)
PEFCR	Product environmental footprint category rule
PEG	Polyethylene glycol
PEO	Polyethylene oxide
PET	Polyethylene terephthalate
PLP	Plastic Leak Project
PPC	Polypropylene carbonate
PVA	Polyvinyl alcohol
t	tonne (metric ton)
TRWP	Tire and road wear particles
Vhc	Vehicle
WBCSD	World Business Council for Sustainable Development

About this report

This report was developed by a joint team from Quantis and EA and reviewed by PLP members and the Advisory Board.

Quantis is a consultancy guiding top organizations to define, shape and implement intelligent environmental sustainability solutions. With renowned leadership in multi-sectorial projects, for over 10 years Quantis has helped industry partners to define metrics-based deployable and actionable solutions. Find more information at https://quantis-intl.com/.

EA is an eco-design center, with expertise in modeling the sources and pathways of macro- and micro-plastics. EA has developed plastic footprint tools for companies, products, countries and individuals. Find more information at http://www.shaping-ea.com/.

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Introduction

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1.1 Context and background

Plastics are widely used materials: between 1950 and 2017, global production of plastics steadily increased to 415,000,000 t/year of which 64,400,000 t/year were generated in Europe (PlasticsEurope 2018). Plastics are produced mainly in the form of pellets, resins, powders, synthetic fibers for textiles, and synthetic rubber for tires and other applications (Boucher et al. 2019b). Intrinsic properties such as low density and high durability make plastics attractive for various everyday applications. Plastics also tend to be viewed favorably from a greenhouse gas (GHG) emissions perspective (PlasticsEurope 2009) since, for example, a light-weight plastic package often generates less GHG emissions over its life cycle than a function-equivalent package made of other materials. Moreover, thermoplastic materials can be easily recycled and reprocessed, making them promising materials in the context of a circular economy (Ellen MacArthur Foundation 2017). However, some plastics are not kept in a circular loop or properly managed at their end-of-life, thus potentially finding their way into the environment, a phenomenon we call leakage.

Plastic leakage is defined as the plastic leaving the technosphere and accumulating in the natural environment.

To increase material circularity, leakage of plastic from the human technosphere must be reduced, and ultimately prevented. Growing urgency and awareness around the issue of plastic leakage is driving companies and public authorities to make bold commitments to reduce their plastic leakage.

To effectively "close the tap"[1] on plastic leakage, stakeholders must be able to detect the leaks within their own industry and supply chain. Clear and reliable information on plastic leakage is needed to ensure that companies can identify hotspots and home in on the most effective interventions at a systemic level. However, until now this information has not been available.

[1] "Close the plastic tap" is a commonly used expression that means reduce the plastic leakage. It is the name of the IUCN program described at: https://www.iucn.org/theme/marine-and-polar/our-work/close-plastic-tap-programme/reports

The Plastic Leak Project (PLP) intends to fill this knowledge gap by delivering new methodologies and metrics to assess plastic leakage within the life cycle assessment (LCA) framework. The PLP provides industry-specific guidance as well as generic datasets to perform plastic leakage assessments.

The PLP thus aims to provide a meaningful contribution to mitigate plastic leakage by supporting companies in identifying the most relevant and fruitful actions and strategies to "close the tap".

1.2 Different sources of leakage: macro- versus microplastics

Several studies have inventoried and quantified various sources of plastic leakage, either at the country or global level (Essel et al. 2015; Lassen et al. 2015; Magnusson et al. 2016). Global plastic leakage is estimated to be on the order of 10 million metric tons (Mt)/year, with calculations ranging from 4.8 Mt/year to 12.7 Mt/year and encompassing one or more leakage sources (e.g., micro- and/or macroplastic, coastal and /or inland) (Jambeck et al. 2015; EUNOMIA 2016; Boucher and Friot 2017; UN Environment 2018).

Plastics enter the environment by one of two core streams: visible macroplastics mainly from mismanaged waste, and mostly invisible primary microplastics released from various sources, such as synthetic clothing during washing.

Macroplastics are defined as plastic fragments greater than 5 mm long. These originate mainly from single use of durable plastics. Such materials tend to be leaked to the terrestrial environment and oceans in countries with less efficient waste treatment infrastructure.

Microplastics are defined as plastic particles smaller than 5 mm and greater than 1 μm in diameter (Ryan et al. 2019). Such small particles are much more pervasive than macroplastics and have more subtle routes to the environment.

Primary microplastics are defined as microplastics lost from the technosphere and released to different environmental compartments as small particles. Some primary microplastics are intentional product additions such as microbeads and scrubbing agents in toiletries and cosmetics like shower gels. Other primary microplastics may stem from the abrasion of large plastic objects during manufacturing, use or maintenance such as the erosion of tires when driving or the abrasion of synthetic textiles during washing. When released through household wastewater or road runoff, primary microplastics can pass through treatment systems and accumulate in rivers and oceans with potentially detrimental effects to ecosystems and human health.

Secondary microplastics are defined as microplastics generated from the degradation of larger plastic items into smaller plastic fragments upon exposure to an aquatic environment.

N.B. Exposure to an aquatic environment not only degrades macroplastics into secondary microplastics, but also fragments primary microplastics into even smaller particles. This fragmentation happens through photodegradation and other weathering processes.

Figure 1.1 summarizes the different sources of macro- and microplastic leakage.

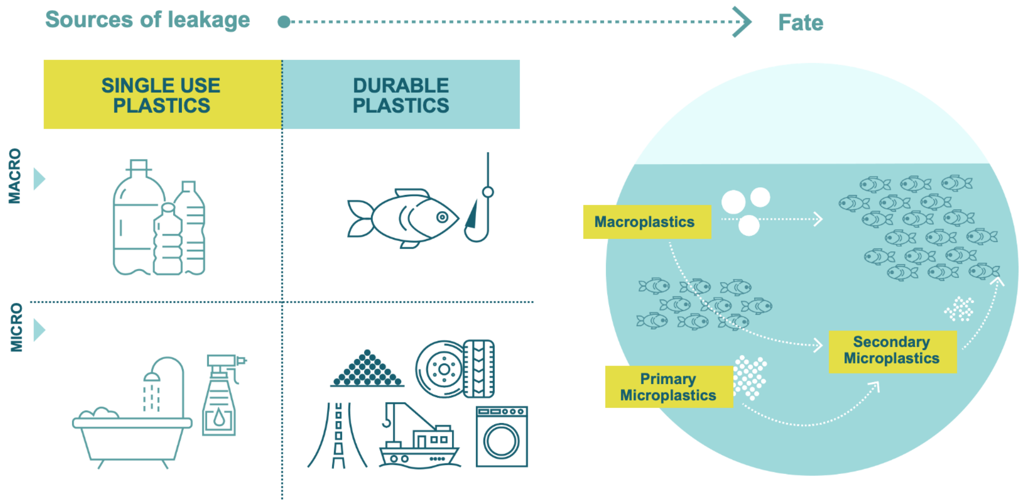

Figure 1.1: Various sources of leakage: macro- and microplastics (Boucher et al. 2019a)

The main sources of plastic leakage are presented in Figure 1.2 and summarized here:

- Coastal mismanaged (macro) plastic waste (MPW): 8 Mt/year. The most commonly cited orders of magnitude for mismanaged plastic waste are published by Jambeck et al. (2015). This research focused on the amount of mismanaged plastic waste likely to be generated by coastal populations (people living within 50 km of shore) across 192 countries.
- Inland mismanaged (macro) plastic waste: 1 Mt/year: Inland mismanaged (macro) plastic waste represents the addition of river (macro) plastics to global plastic leakage, which can fluctuate by season and location. Lebreton et al. (2017) estimate that between 1.15 and 2.41 Mt of plastic waste currently enter the ocean every year from rivers, and at least 0.79 to 1.52 Mt per year reaches oceans from inland areas. Therefore, 1 Mt is used as a preliminary estimate for

inland mismanaged (macro) plastic waste excluding waste generated by coastal populations to avoid double counting.

- Microplastics: 1.5 Mt/year of plastic enters the marine environment in the form of primary microplastics. The main sources of primary microplastics are marine coatings, road surface marking, tire wear, textile synthetic fibers, micro beads from personal care products, dust from household plastic materials, and products containing synthetic polymers. For example, Boucher et al. (2017) estimate that close to two-thirds (63%) of microplastic released to oceans originate from the abrasion of synthetic textiles during washing (35%) and the erosion of tires while driving (28%). When considering microplastic released to European rivers, Siegfried et al. (2017) calculate that tire abrasion represents 42% of the total microplastic load transported by rivers to seas, followed by plastic polymer-based textiles (29%), synthetic polymers in household dust (19%), and personal care products (10%).
- The fishing and aquaculture sectors are a potential source of plastic leakage; however, studies quantifying the leakage on global scale are few. It is estimated that 0.6 Mt/y of fishing gear is lost at sea (Circular Ocean project[2]).

Based on the information above and on industry representation of the PLP consortium/membership, the PLP focuses on plastic products and packaging, textile washing, pellet production, and tire abrasion. These represent not only the principal sources in terms of magnitude, but also the most well documented sources for which underlying data is available.

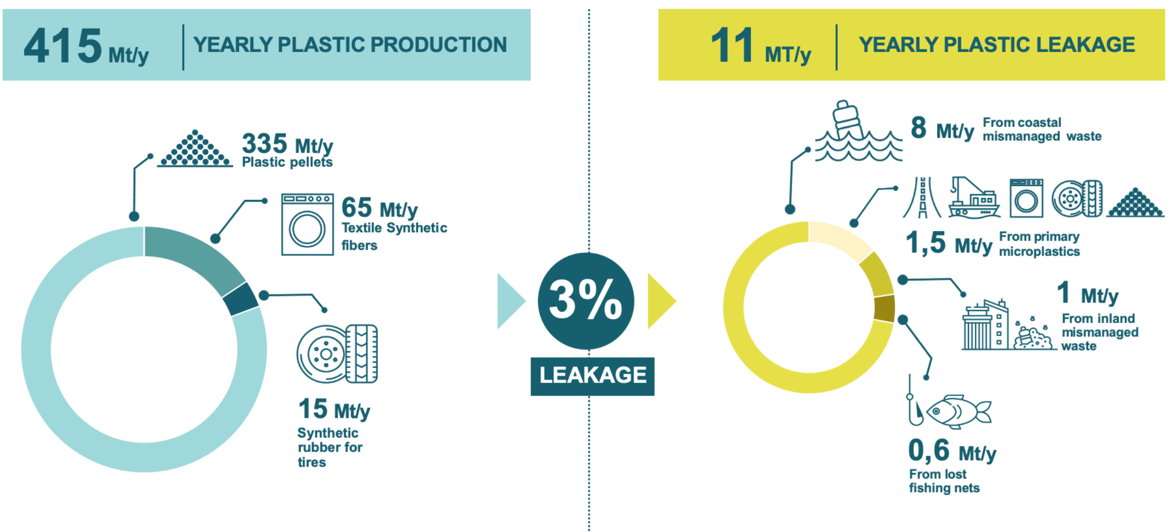

Figure 1.2: Plastic production and plastic leakage by source: current best estimates worldwide (Boucher et al. 2019b)

[2] http://www.circularocean.eu

1.3 Need for better metrics

Today, in an effort to abate the ocean plastic crisis, many decisions are made without scientific justification. Although the magnitude of global plastic leakage has been estimated (Jambeck et al. 2015), given limited time and resources, taking action requires more specific and granular information on regional and industry leakage and relevant solutions. Currently there is no common vocabulary nor grounded methodology to perform a plastic leakage assessment for a given product or industry. The need for harmonized standards and methods is acute and this urgency is recognized by scientists, the international community, and sustainability practitioners (Sonnemann and Valdivia 2017; UNEA 2017; Boucher et al. 2019b).

To fairly evaluate the impacts of plastics within a comprehensive environmental framework and avoid impact trade-offs, life cycle methodologies will need to be bolstered by standardized and widely-accepted plastic leakage accounting.

Better metrics to account for plastic leakage impacts include (Boucher et al. 2019a):

- Metrics to quantify and characterize plastic items and particles existing in the environment: "How much plastic is present, where is it, and what effects does it have?"
- Metrics to quantify and characterize plastic flows leaking into the environment: "How much plastic is leaking and from where?"
- Metrics to assess environmental impacts resulting from the leakage: "What are the environmental impacts resulting from plastic pollution?"
- Metrics to assess the consequences of leakage through monetary valuation: "How do the environmental impacts of plastic litter rank financially among other environmental issues?"

In this context, the PLP has developed metrics to classify and measure plastic flows leaking into the environment. This is a paramount step toward solving the growing problem of plastic pollution.

1.4 State of the art

Although there is no consensus-based scientific metric to measure plastic leakage, several methodologies to assess the environmental impact of plastic use within a system (e.g., industry, company, product or country) have been developed in recent years. The International Union for Conservation of Nature (IUCN) provides an overview of seventeen key methodologies (Boucher et al. 2019a), which are available as tools or guidelines for business- and product-level assessments. They include national and regional methodologies to be used by the public sector, and individual-level footprint methodologies to be used by citizens and consumers. They are classified by output metric (e.g., quantity of plastic used or wasted, quantity of plastic leaking from the technosphere into the environment, measure of environmental impacts generated by the plastic leakage), actionability (e.g., plastics differentiated by polymer and format, leakage assessed by geography with regionalized factors), methodology scope (entity such as business, country or region or product life cycle) and level of maturity based on the year of release. This review shows that:

- The field of plastic leakage assessment is rapidly progressing thanks to better understanding of leakage pathways and better data. In particular, specific studies have been undertaken to estimate in detail the plastic leakage resulting from specific sectors and products (e.g., Unice et al. (2019a) for plastic leakage from tire abrasion; Henry et al. (2018) for microplastic pollution from textiles). The development of a plastic leakage metric is thus very timely.
- The knowledge of impacts resulting from plastic leakage is only just emerging. There is to-date no robust assessment method available.

While we acknowledge that the ultimate goal is to fully integrate plastic pollution factors into the LCA framework, the PLP project at the time of this publication is focusing on the inventory stage of plastic leakage.

Other initiatives are being launched to tackle the impact assessment stage. One example is the MARILCA (Marine Impacts in LCA) working group, which was formed jointly by the UN Environment Life Cycle Initiative and the Forum for Sustainability through Life Cycle Innovation (FSLCI) to foster and develop methodologies for impact assessment of plastic leakage in LCA. The work of MARILCA is complementary to that of PLP, given that the PLP methodology can serve as a starting point for the plastic leakage impact assessment framework. The results of these combined initiatives will provide the building blocks for full integration of plastic leakage impacts among LCA indicators in the future.

1.5 Plastic Leak Project

The PLP is a multi-stakeholder initiative created to develop better metrics to help shape operational solutions and effective actions to address the plastic pollution crisis. Convened by Quantis and EA, this precompetitive global initiative takes an in-depth look at the circular economy of plastics, assesses existing knowledge gaps, and develops a methodological guide to enable companies to locate and assess plastic leakage along their value chains.

Figure 1.3: Plastic Leak Project conveners

The PLP was co-founded by Quantis and EA, and its membership includes 23 organizations across several industries. The members include Adidas, Arla Foods, Braskem, CITEO, Cotton Incorporated, Cyclos, Decathlon, DOW, Eastman, Enel X, European Bioplastics, European Tyre & Rubber Manufacturers' Association, International Wool Textile Organization, Mars, Incorporated, McDonald's Corporation, PlasticsEurope, RadiciGroup, Sympatex Technologies, and The Woolmark Company.

Figure 1.4: Plastic Leak Project members

To help guide the project, a strategic committee was assembled, comprised of the international organizations International Union for Conservation of Nature (IUCN), the Life Cycle Initiative, the United Nations Environment Programme (UNEP) and the World Business Council for Sustainable Development (WBCSD).

Figure 1.5: Plastic Leak Project strategic committee

Co-founders, strategic committee and partners are supported by an advisory committee presented in Figure 1.6. The advisory committee provides scientific and technical input at various stages of the project by reviewing the guidelines and contributing data and sectoral expertise.

Figure 1.6: Plastic Leak Project advisory committee

Objective of the guidance

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2.1 Overview of approach

The objective of this document is to provide a clear methodology as well as supporting data to enable companies to perform a plastic leakage assessment of their product, service and/or organization.

To understand the process followed by the PLP in 2019 to develop this methodology, the PLP's workflow steps are summarized in Figure 2.1 and further described in the sections that follow.

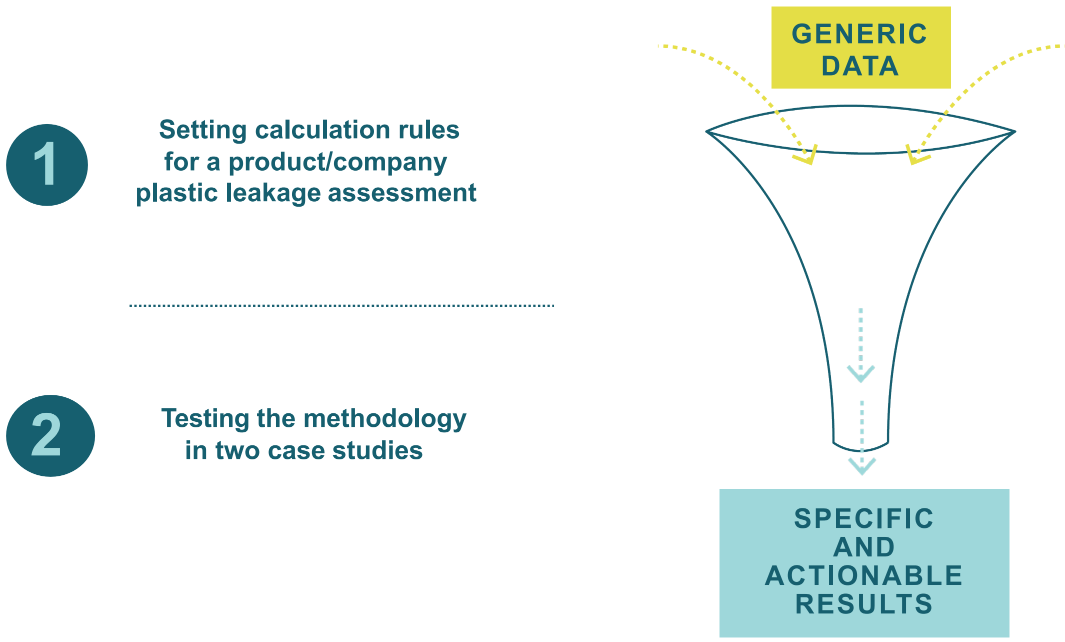

Figure 2.1: Workflow of the Plastic Leak Project

The 2019 PLP scope of work deliverables are:

1) This methodological report that includes generic calculation rules for a plastic leakage assessment plus specific calculation rules for macroplastics (namely packaging and other plastic products), microplastics generated through textile washing, and tire abrasion, as well as supporting generic data, and

2) Two case study reports applying the methodology to evaluate the plastic leakage of specific product and corporate value chains.

The PLP methodology does not account for potential impacts on human health or biodiversity from plastic leakage or leakage from materials other than plastic and rubber.

2.2 Calculation rules for a product- or corporate-level plastic leakage assessment

This report provides guidance for calculating micro- and macroplastic leakage quantities at each life cycle stage and at both product and corporate levels, ultimately for including them in environmental assessments. In addition, four sector-specific approaches are provided to supplement the general guidance for the following sectors:

- Plastic products and packaging (due to waste mismanagement)
- Textiles (due to textile washing)
- Transport (due to tire abrasion)
- Pellet production

The goals of these guidelines are to:

- provide data and rules based on state-of-the-art knowledge to ensure consistent assumptions, measurements and calculations
- evaluate benefits of key interventions
- reduce leakage, and
- support comparable environmental claims when modelling plastic leakage for product and corporate assessments

The benefits of a standardized approach include verifiability, relevance, and consistency of results. This guidance builds upon original research by the PLP team as well as the work of other scientific groups and researchers, as acknowledged throughout the report and in the reference section.

2.3 Case studies

The calculation rules and underlying datasets for plastic leakage assessment have been applied in two case studies:

- A product plastic leakage assessment on a textile garment (a three-layer hard shell outdoor jacket) manufactured by Sympatex Technologies, and
- A corporate plastic leakage assessment for the Arla Foods dairy company

Methodological principles

3

3.1 What is leakage and how can it be modelled?

The generic term *leakage* is defined as a quantity (in grams) of plastic leaving the technosphere and ending up in the natural environment. A plastic leakage assessment accounts for different types of plastics as described in 11.1. Plastics are characterized by the type of thermoplastic or thermosetting polymer, as fossil or bio-based, and including synthetic and natural rubber.

Leakage is a result of both **loss** and **release** through a **transfer and redistribution pathway**.

This section describes in more detail each of these elements in leakage modelling, which is illustrated in Figure 3.1 and further detailed in Figure 3.2.

Figure 3.1: Key stages of the plastic leakage modelling | overview

3.2 Loss

Loss is the quantity of plastic that leaves a managed product or waste management system. The loss is constituted by the fraction of plastic materials that is detached from the product during manufacturing, use or transport (for microplastics), or mismanaged waste (for macroplastics), i.e., the fraction leaving the technosphere. A properly managed waste management system is defined as one where little or no macroplastic leakage is expected to occur, including systems of recycling, incineration or sanitary landfill. Losses are specific to various sources and activities (e.g., the processes of losing plastics into the environment through abrasion, weathering or unintentional spills during production, transport, use, maintenance or recycling of products containing plastics, or from littered plastic packaging). The main sources of loss considered in this project are tires, synthetic textiles, plastic pellets and other sources for **microplastics** (e.g.,marine coatings, personal care products, city dust), as well as plastic packaging, plastic products and other sources (e.g., infrastructure, agriculture, fishing devices) for **macroplastics.**

3.3 Transfer

Different types of **transfer pathways** lead from loss to release. Transfer pathways represent the main routes through which plastics are released from the technosphere to a nature compartment. Six transfer pathways are considered in the PLP: wastewater (e.g., laundering of synthetic textiles), road runoff (e.g., tire abrasion), air (e.g., microplastics released from synthetic textiles), uncollected waste (e.g., littered waste, fly tipping), poorly managed waste (e.g., non-sanitary landfill, illegal dumping) and the direct pathway (e.g., macroplastic waste dumped in rivers, fishing nets lost at sea). Uncollected or poorly managed waste may be collected and recycled/downcycled by waste pickers through an informal collection system if the waste is valuable to the picker; in this case, the waste is not considered lost as it goes back to a properly managed waste system.

3.4 Initial release

The initial release compartment is the environmental medium to which the plastic is released through a single pathway or a combination of multiple pathways.

The following **initial release compartments** are considered throughout this methodology:

- **Release to ocean** represents plastic released to oceans.
- **Release to fresh water** represents the initial release to rivers or lakes, for example the release of effluent after wastewater treatment to a body of fresh water.
- **Release to soils** represents plastic released to soil, for instance via the spreading of sewage sludge on agricultural soils.
- **Release to terrestrial environment** represents plastic released to a terrestrial environment other than soils, such as plastic deposited and stored in dumpsites, plastics deposited on buildings or trees, and littered plastic packaging.
- **Release to air** represents plastic released to air, such as plastic dust from tire abrasion or synthetic textiles (although this latter type is not included in the methodology due to lack of data).

3.5 Redistribution

The redistribution of plastic from an initial compartment to its final compartment covers different types of transfers such as leaching, transport in freshwater bodies, or wind blowing. The PLP currently models two redistribution mechanisms:

- The **transport of plastic by rivers**, as it is expected that microplastics may be partly transferred in oceans and partly deposited in river sediments.
- The **redistribution of microplastic emitted by air onto freshwater and soil**. We consider that all microplastics emitted into air are ultimately deposited in another final release compartment.

3.6 Final release

The **final release compartment** is the final medium to which plastic is transferred after the redistribution stage.

The following **final release compartments** are considered throughout this methodology:

- **Release to ocean** represents plastics released to ocean, including what is initially released in oceans plus what is redistributed from other compartments in the time frame considered (1 year).
- **Release to freshwater** represents the fraction of the initial release into freshwater that is assumed to remain within the compartment over time. This includes microplastic accumulated in river sediments and lake beds. The time horizons defined in this study are explained in section 3.8.
- **Release to soil** represents plastics released to soil, for instance microplastic captured in sewage sludge spread on agricultural soils, plus microplastic deposited after its initial release in the air compartment.
- **Release to terrestrial environment** represents plastics released to terrestrial environments other than soils, such as macroplastic deposited and stored in dumpsites, macroplastic deposited on buildings and trees, and littered macroplastic packaging.

Figure 3.2 summarizes the losses, transfer pathways and release compartments included in these guidelines. The arrows representing the connections between the boxes for each source and pathway are further detailed in the sectoral guidelines of this report, including calculation routes and supporting data.

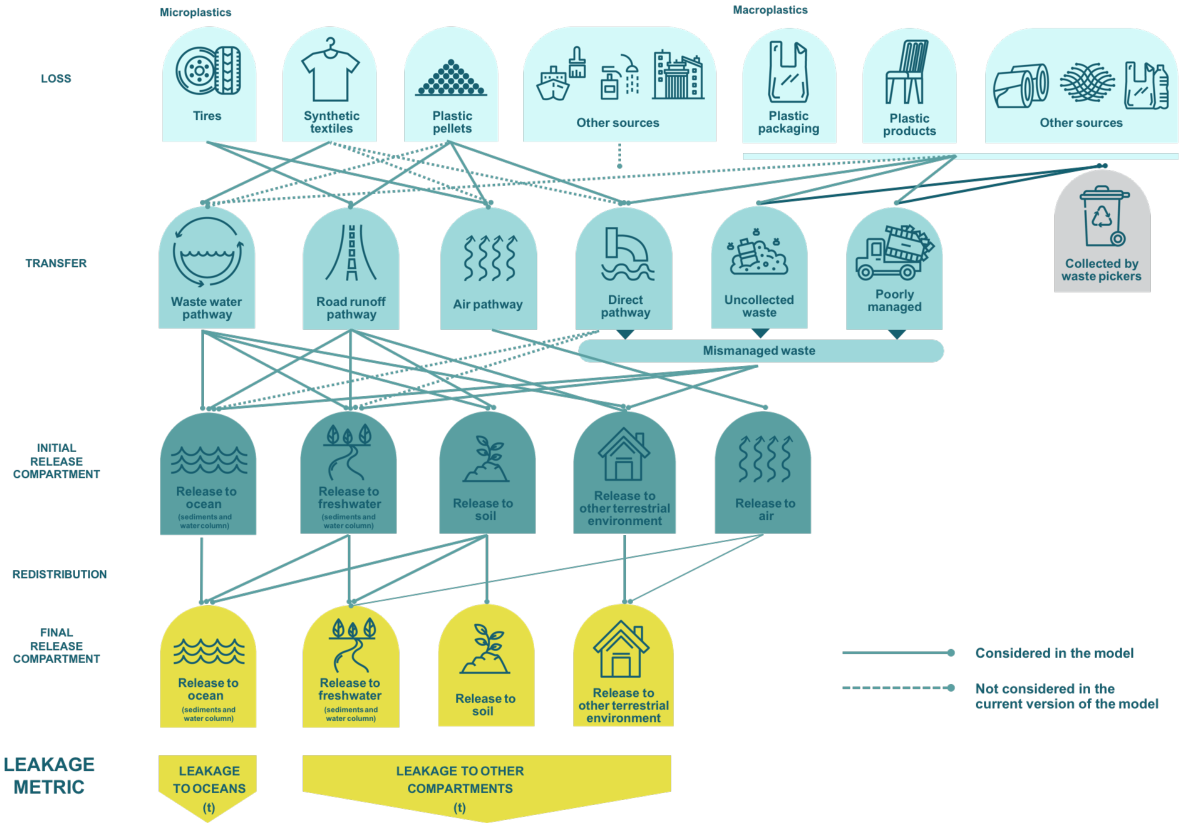

Figure 3.2: Key stages of the leakage modelling | detailed view

The links between the different boxes are described in more detail in sections 6, 7, 8 and 9.

The leakage modelling framework presented in Figure 3.2 yields two central leakage metrics: “leakage to oceans” i.e., the quantity of plastic accumulated in oceans, and “leakage to other compartments”, i.e., the sum of the quantities of plastic accumulated in freshwater, soil and other terrestrial compartments.

Two important notes:

- In the current version of the model, final release to freshwater is exclusively the plastic accumulated in river sediments, as the fraction present in water is considered to be flushed out to an estuary over time, and therefore expected to culminate in the "ocean final compartment"3
- In this model, an air compartment is not included among the final release compartments since it is assumed that anything emitted to air is eventually deposited to a non-air final compartment. However, it is important to note that the continual release of particles in air may lead to a steady state concentration affecting organisms and human beings. This effect should be accounted for when assessing impacts resulting from plastic leakage, which is beyond the scope of the PLP.

[3] Estuaries are not considered a final compartment: it is estimated as a first assumption that 100% of plastics reaching the estuaries ultimately culminate in the ocean.

3.7 How to account for plastic fate?

Assessing the fate of a pollutant in the environment after it is emitted is the first stage of impact assessment (traditionally followed by exposure and effect assessments in Life Cycle Impact Assessment (LCIA)). This work focuses on inventory of plastic emissions and not on the resulting impacts, e.g.,impacts on human health or biodiversity.

3.7.1 Description of the full fate

Strictly speaking, redistribution from initial to final compartment should be considered a first level of fate (e.g., similarly to the USEtox model (Rosenbaum et al. 2008)). Indeed, the full fate of leaked plastic would include three key elements in total as illustrated in Figure 3.3:

i) **Redistribution of plastics between environmental compartments:** the redistribution of plastic from initial release compartment (i.e., when the plastic leaves the technosphere) to final release compartment, as described in section 3.5. In this guidance, a default time horizon of one year is used for the fate modelling, i.e., redistribution occurring within one year of release.

ii) **Fragmentation of macroplastic into secondary microplastic**: the fragmentation mechanism is not considered in the PLP methodology due to lack of data on fragmentation rates.

iii) **Degradation of plastics**: different polymers have different environmental lifetimes as a result of their different degradation rates. Our assessment of the environmental lifetime of plastics is key to evaluating the magnitude of plastic leakage; indeed, plastics with longer lifetimes can affect the environment over a longer period, and thus be more harmful. In practice, this means that 1 kg of plastic with a lifetime of one year should not be accounted for in the same way as 1 kg of plastic with a lifetime of 100 years. This is especially important when comparing biodegradable plastics with conventional plastics as they may have different residence times in the environment. The residence time is defined as the length of time the plastic remains in an environmental medium such as soil, sea water, freshwater or air. Similar to how multimedia models cover the impact pathway of chemicals emitted in the environment (e.g., USEtox

(Rosenbaum et al. 2008)), this stage of fate assessment represents the compartment-specific residence time of a plastic. The potential release of additives during plastic degradation can be assessed as toxic in an LCA study. However, this effect is not included in a plastic leakage assessment. The fragmentation of a polymer into smaller pieces cannot be considered as biodegradation.

The key time-related milestones for a plastic leakage assessment are:

- t_0 is the moment a plastic arrives in its initial natural compartment
- t is the moment it reaches its final natural compartment
- t+1 corresponds to one year after the arrival in the final release compartment and is considered only when assessing full fate

Times t and t+1 are further defined in section 3.8.

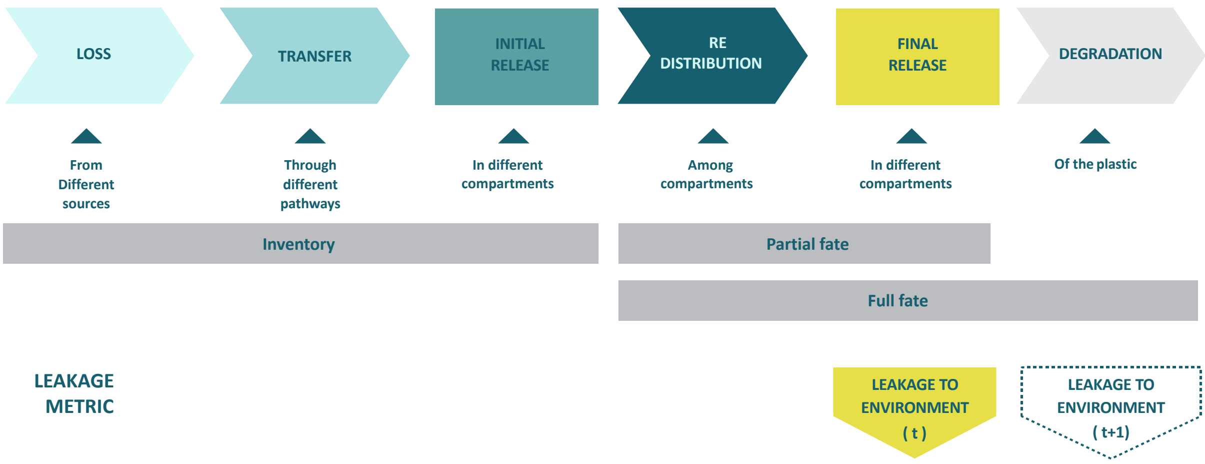

Figure 3.3: Key stages of the plastic leakage modeling | integration of fate

3.7.2 Degradation of plastic

Similar to the toxic impact of organic substances in multimedia models (Rosenbaum et al. 2008), the metric for the lifetime of plastic to complete mineralization is a pivotal parameter in initial fate calculations[4].

Table 3-1 presents the biodegradation rates after one year[5] of specific polymers in different natural compartments. Among values available in the research literature, only the biodegradation rates measured via standardized methodologies (ISO 17556, ISO 14851, ASTM D5988 and ASTM D6691) and reflecting natural conditions were selected. This table will need to be updated and completed as research develops.

Table 3-1: Polymer biodegradation after one year in natural compartments. The literature review resulting in this table can be found in the Excel file PLP_Biodegradation_rate_literature_review.

Type of plastic	% degradation			Publications
	Soil	Sea water	Freshwater	
PP	2	-	-	Gómez and Michel (2013)
PS	2	-	-	Gómez and Michel (2013)
PE oxodegradable	7	-	-	Feuilloley et al. (2005)
PHA	55	-	-	Gómez and Michel (2013)
PHB	-	80	-	Thellen et al. (2008)
PHBV	80	90	-	Thellen et al. (2008; Arcos-Hernandez et al. (2012)
Mater-Bi	72	-	-	Feuilloley et al. (2005); Tosin et al. (2019)
Polyester	13	4	2	Li et al. (2010); Zambrano et al. (2019, 2020)

The comprehensive literature review is documented in Appendix A and the Excel file PLP_Biodegradation_rate_literature_review, and presents all articles measuring the

[4] There are knowledge gaps on plastic degradation rates but it is understood that degradation needs to be defined based on **full mineralization of the polymers** and not based on simple physical degradation leading to a reduction in size.

[5] When an experiment tested biodegradation over a period shorter than a year, the value was assumed to be representative of what the biodegradation would be after a year.

biodegradation rate of a plastic by weight loss or respiratory methods. The biodegradation rates of certain polymers were measured, but not according to standardized methodologies, and these are PE, PET, TRWP, Polybutylene sebacate, PCL, PBAT, Poly[(3-hydroxybutyrate)-co-(3- hydroxyvalerate)], PBS, Nylon 4, BTA, PBSA, PEA, PEG, PVA, PEO, and PPC.

Limitations

- These standards do not take into account how additives may alter the biodegradation rates or their impact on the environment; nor do they reflect what happens in a natural compartment (as the testing is carried out in a laboratory), thus results are to be interpreted with caution. Table 3-1 presents the percentage of degradation after one year; however, the residual material that does not biodegrade remains in nature. Little is currently known about residual polymers that do not biodegrade, notably whether they biodegrade eventually or merely fragment into smaller pieces. Fragmented microplastics are likely to pose a hazard to ecosystems and humans.
- It is important to note that even when polymers have a high rate of biodegradation, it does not mean they will not negatively impact the environment. Indeed, plastics can have adverse impacts on the environment regardless of biodegradation (e.g., by being ingested by animals).

The plastic leakage t+1 indicator based on estimated biodegradation is optional. It can be used to compare polymers or products using different polymers. If a specific polymer's degradation rate is not available in this report, it will need to be estimated by the organization performing the study.

The ultimate goal of assessing plastic leakage is to eliminate leakage completely by taking action (examples of measures are given in Appendix F). Indeed, plastics can harm the environment from the moment they leak; even a plastic that would be fully mineralized within a year may be ingested by an animal before it starts its “rapid” biodegradation. The t+1 indicator may be used to evaluate residual littering, or to choose the optimal polymer for a specific use. For instance, a manufacturer could choose a polymer that biodegrades quickly as raw material for a take-away packaging.

Plastic degradation in the environment

The measure of a plastic's lifetime is defined to include both the fragmentation of polymers into monomers and monomer conversion to CO_2. New methods need to be developed to measure the period of time required for both stages. The processes involved in plastic degradation are presented in more detail below.

Plastic degradation can be defined as a "chemical change that drastically reduces the average molecular weight of the polymer (Andrady 2011)". Plastic thus undergoes a loss of mechanical integrity due to environmental factors before undergoing mineralization (generally via microbial-mediated biodegradation) when the carbon in the polymers is converted into CO_2 (or incorporated into biomolecules in some cases). There are four mechanisms by which plastics degrade in the environment: photodegradation (sunlight provides the energy to break the molecular bonds), thermo-oxidative degradation (slow oxidative breakdown of the polymer chains at moderate temperatures), hydrolytic degradation (breaking of the polymer chains by water molecules) and biodegradation by microorganisms (conversion of the carbon chains with a low enough molecular weight to CO_2 or incorporation into biomolecules) (Andrady 2011). Some of these mechanisms can occur simultaneously or not at all, depending on the properties of the polymer and of the environmental compartment. When these processes go to completion and all the organic carbon in the polymer is converted, it is referred to as complete mineralization (Eubeler et al. 2010). However, this entire process is slow (Edge et al. 1991; Allen et al. 1994).

The factors influencing the degradation rate of polymers are numerous and can be related to inherent properties of the polymers or the object (crystallinity of the material, additives within the polymer, shape and surface morphology of the object), as well as environmental conditions (temperature, nutrient, microbes, UV light exposure, oxygen availability, salinity, pH, location in the water column or in the ground). Thus it is very hard to predict the degradation rate and there is much variability of degradation rates even within the same polymer type and environmental compartment.

3.8 What are the different time horizons?

Different time horizons may be considered in a plastic leakage assessment, as already illustrated in Figure 3.4.

First, the **functional unit** can be related to a time horizon in the case of a corporate assessment, assessing the leakage from one year of activity. This has no direct influence on leakage modelling, but dictates how the data should be collected, as well as the reference period for a corporate leakage assessment. In the case of a product assessment, the functional unit should be defined case by case, with specific timeframes to be defined.

Furthermore, the **loss, initial** and **final release** as well as the **fate** do not happen simultaneously.

The **transfer** occurring between the **loss** and **the initial release** (i.e., when the plastic leaves the technosphere) is not instantaneous. For example, a plastic fiber lost at the outlet of a washing machine may take weeks or months to travel through the sewage system and waste water treatment plant before being spread as fertilizer sludge on fields. When the transfer has occurred and the initial release takes place, we consider $t_0=0$ (start of the fate process).

A **redistribution** of the plastic may occur between the **initial release compartment** and the **final release compartment**. The time horizon considered for this redistribution is undefined (t), and the impacts resulting from the plastic in the different compartments should be integrated over time (which is not in the scope of the PLP methodology). For instance, microplastics initially released in a river may partly settle into sediment and not be further transported to the ocean compartment. Thus a set of transport ratios for different types of microplastics is proposed in the PLP guidelines, based on research literature and expert judgment, focusing on the river transport (as no data is currently available for the potential redistribution amongst other compartments).

The **full fate** includes the plastic degradation. A time horizon of one year has been chosen as an arbitrary reference[6] to estimate the amount of plastic remaining after this time frame. The time horizon for the full fate thus corresponds to t+1.

In summary, the initial release is represented by time zero $\mathbf{t_0}$ within the framework. The final release occurs after an undefined time **t**. The full fate starts after the initial release at t_0 and is assessed one year after the final release at **t+1**.

[6] This time frame has been defined due to low data availability on degradation rates for longer time frames. It should be updated when more research data on degradation rates become available, e.g.,to 50 or 100 years.

Figure 3.4 presents the release and the fate time horizon chosen as reference in this plastic leakage methodology.

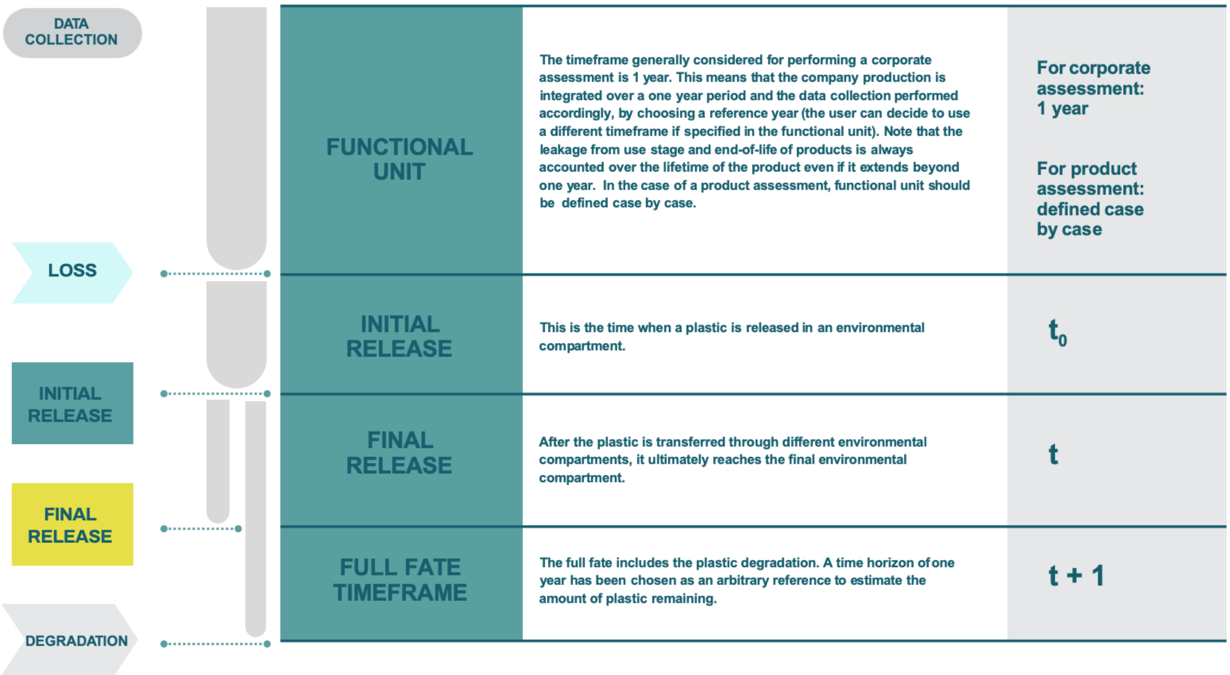

Figure 3.4: Plastic leakage time horizons

3.9 Which leakage metrics shall be used?

3.9.1 Different perspectives on plastic leakage

The plastic leakage metrics can be analyzed from different perspectives, which provide various angles to understand the leakage hotspots. Hotspots are defined as a country, product, polymer or value chain stage that contributes significantly, directly or indirectly, to the leakage.

Figure 3.5 shows mandatory and optional perspectives for reporting a product or corporate footprint. Each perspective addresses one specific question as summarized in Figure 3.5.

The **mandatory perspectives** are listed below.

- The **key results** perspective answers the questions:
    - What is the leakage along my value chain?
    - In which environmental compartments?
    - Key results include total leakage, **leakage to the ocean** and **other environmental compartments,** with a split between macro- and microplastics as well as the **plastic leakage intensity indicator**.
- The **value chain** perspective answers the questions:
    - Where does the leakage occur along the value chain?
    - In which environmental compartments?
    - Where are the hotspots in the life cycle stages, including material procurement, production, product use, product end-of-life and transport for each release compartment defined in 3.6.?
- The **country** perspective answers the questions:
    - In which country does the leakage occur?
    - What is the plastic leakage intensity?
    - Furthermore, it provides a hotspot analysis of country leakage for each final release compartment.
- The **optional perspectives** may be analyzed if they add value based on the type of study. The following optional perspectives can be explored:

    - The **market** perspective answers the questions:
    - Which market is responsible for the leakage?
    - What is the plastic leakage intensity?
    - Furthermore, it provides insight on the market responsible for the leakage. It is relevant in case products are distributed among several markets. All the leakage occurring upstream and downstream relative to the consumer is allocated to the market where / from where a product is distributed. For example, the leakage occurring during the production stage of textile produced in China is attributed to Switzerland, where the product is ultimately distributed and used.
- The **product** perspective answers the question:
    - Which products are contributing to the leakage?
    - Furthermore, it is relevant in the case of a corporate assessment of a company with a large product portfolio.
- The **polymer** perspective answers the question:
    - Which polymers contribute to the leakage?
    - It is relevant in case different polymers are involved in a product value chain or corporate activities. It displays the plastic leakage hotspots per polymer and life cycle stage.
- The **fate** perspective answers the question:
    - How much plastic will remain after 1 year?
    - This is relevant in the case of comparative assessment of two products made of polymers with different degradation rates. It provides plastic leakage results in a life cycle stage perspective after 1 year of polymer degradation in different final release compartments. Examples of degradation rates are described in section 3.7.

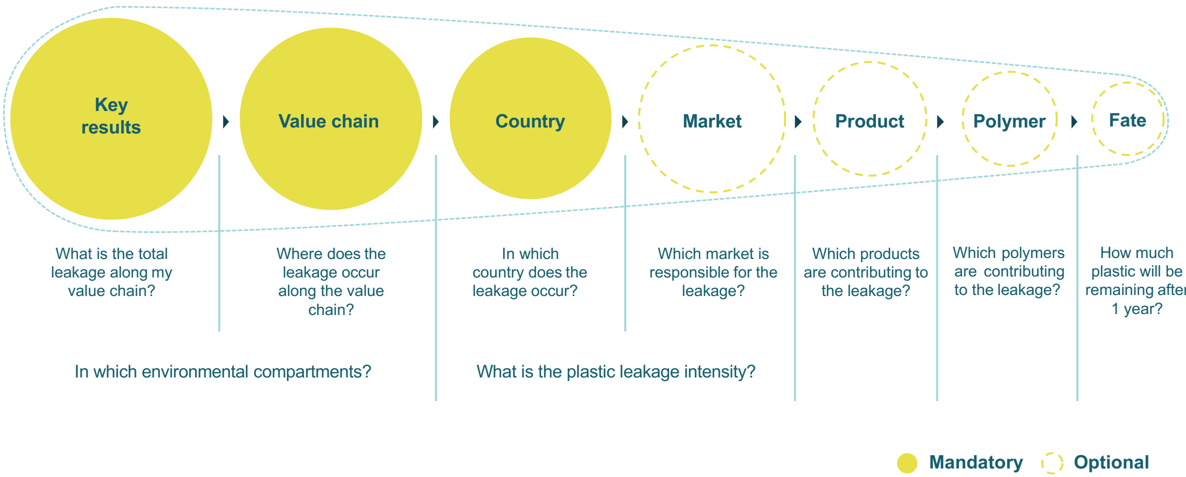

Figure 3.5: Different perspectives on plastic leakage

Examples of recommended results to be communicated above are shown in the case studies presented in section 15.

3.9.2 Key results

The key results perspective shows aggregated metrics of the overall plastic leakage generated by a product life cycle or a corporate activity. As shown in Figure 3.6, it should be expressed as **a single metric** or as **two metrics split between leakage into the ocean and leakage into other environmental compartments**. The share of macroplastics versus microplastics should be broken out.

A **plastic leakage intensity indicator** should be presented in case the macroplastic leakage is a hotspot of the plastic leakage assessment. A plastic leakage intensity indicator can be calculated as the ratio of the mass of macroplastic *leaked* to the mass of macroplastic *used* to provide preliminary insight into the scale of plastic leakage at the product or corporate level.

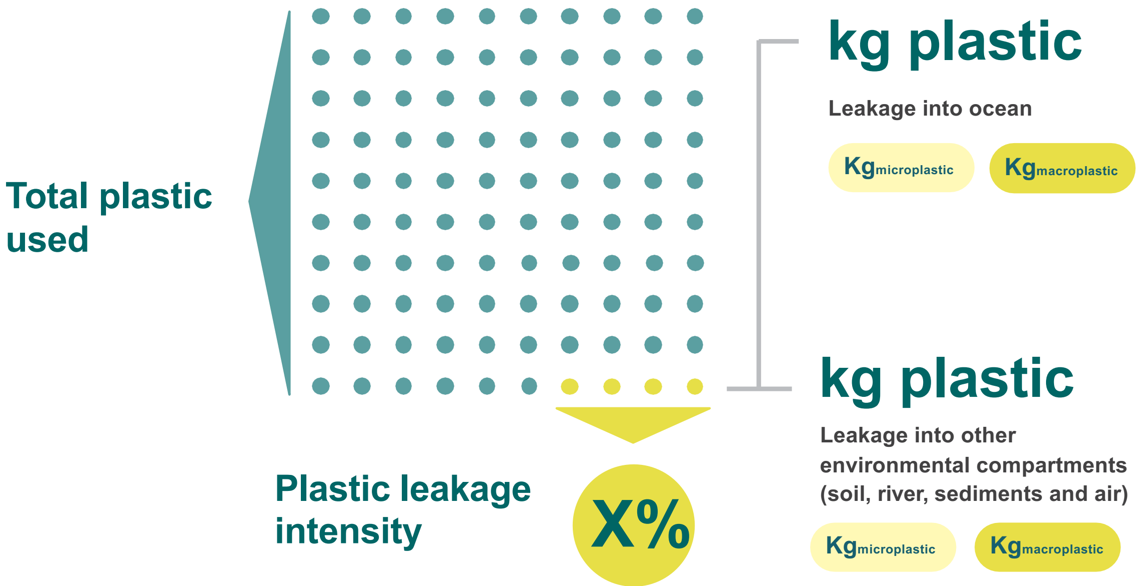

Figure 3.6: Example of display for a plastic leakage assessment key results

3.9.3 Value chain perspective

Additionally, the plastic leakage assessment can be calculated by life cycle stage according to the framework below, to standardize accounting, improve transparency, and clearly delineate responsibility. Leakage occurring along all life cycle stages should be estimated. However, if there is no leakage at a given life cycle stage (e.g., no leakage during the use stage for a food product), that stage does not need to be included in the reporting.

- **Suppliers** includes leakage occurring upstream at supplier sites or linked with the manufacturing of other product or packaging components. Example: plastic loss at a farm due to agricultural practices when assessing the leakage related to a dairy product manufactured remotely from the farm's milk.
- **Own production** corresponds to direct sources that are owned or controlled by the company. Example: synthetic microfiber leakage resulting from production occurring at owned facilities.
- **Product use** includes plastic leakage at consumer, for instance during textile washing.
- **Product end-of-life** includes plastic leakage from a plastic product or packaging disposal, for example a littered packaging or a jacket disposal. This is the stage that has drawn the most attention in the scientific community when referring to plastic leakage.
- **Transport** refers to indirect plastic leakage stemming from tire abrasion during all road transport throughout the different stages of the product life cycle or cycle of corporate activity. This includes transport from suppliers to the manufacturing site, and transport from the manufacturing site to a distribution center, retailer and ultimately the user.

The framework above includes direct and indirect components, covering different levels of responsibility the company may have on plastic leakage:

- The component that the company can **control**, i.e., when leakage arises from infrastructure or processes owned by the company such as material consumption, pollutant emissions, and impact directly generated by the company or the product itself.
- The component that the company does not directly control but could **influence**, for example, by raising awareness and organizing campaigns to try to change the way consumers or suppliers behave (i.e., when the leakage arises from suppliers, transport, usage or end-of-life, defined as third parties that are not owned by the company or not directly resulting from the product design).

Also, solutions implemented at the production stage (e.g., for textiles) may have an influence on microplastics leakage during the use phase (e.g., for washing)

Differentiating what can be controlled versus what can be influenced enables setting a pragmatic and effective action plan on the basis of the plastic leakage calculations. This plan needs to be defined according to i) the magnitude of leakage reduction and ii) the ease of implementation. In fact, actions related to the component that can be directly controlled are usually easier to put in place than actions related to the influenced component. For these reasons, we recommend differentiating between controlled and influenced components when calculating plastic leakage.

Figure 3.7 presents these different life cycle stages.

	Influence	Control	Influence		
PRODUCT AND COMPANY ASSESSEMENT	**SUPPLIERS**	**PRODUCTION**	**PRODUCT USE**	**PRODUCT END-OF-LIFE**	**TRANSPORT**
	All indirect plastic leakage from suppliers (i.e. a process not directly owned by the company but potentially influenced).	Direct plastic leakage from the production (when company-owned facilities).	Direct plastic leakage from the product use and maintenance.	Direct plastic leakage from the product end-of-life.	Indirect plastic leakage from transport (abrasion of tires) *Note: in the case of a tyre manufacturing company, the emissions are accounted for in the « product use » category*
Company examples	• Agricultural plastic used in farms (when farms are not owned by the food company) • Synthetic microfibers generated by yarn manufacturing if a textile company is buying yarn from a supplier (for yearly production)	• Loss of plastic pellets during plastic packaging manufacturing • Loss of fibres during textile fibres production, for all t-Shirts produced by the company over 1 year	• Leakage from household washing over the lifetime of sold textiles (for the different markets)	• Leakage from all mismanaged waste in the different markets/countries where the company is selling products	• All transport from suppliers
Product examples	• Packaging leaked at suppliers site, e.g. for a component of the product externalised • Synthetic microfibers generated by yarn manufacturing if a textile company is buying yarn from a supplier (for 1 T-shirt)	• Loss of primary pellets during a product manufacturing • Loss of synthetic fibres during textile production for 1 T-Shirt	• Shedding of synthetic textile fibres during washing, for 1 T-Shirt	• Littered packaging for a given plastic packaging, for different markets • Synthetic t-shirt disposal in an inappropriately managed landfill or dump	• Transport associated with a product up- and downstream stages of its lifecycle

Figure 3.7 : Life cycle stages to be included in the system boundaries of a plastic leakage assessment

The plastic leakage shall be expressed per life cycle stage and per environmental compartment as presented in Figure 3.8. In this project, we limit macroplastic release to the terrestrial environment and oceans, while microplastics can be released additionally to freshwater sediments and soil. Only microplastics can be released during the use and the transport stages.

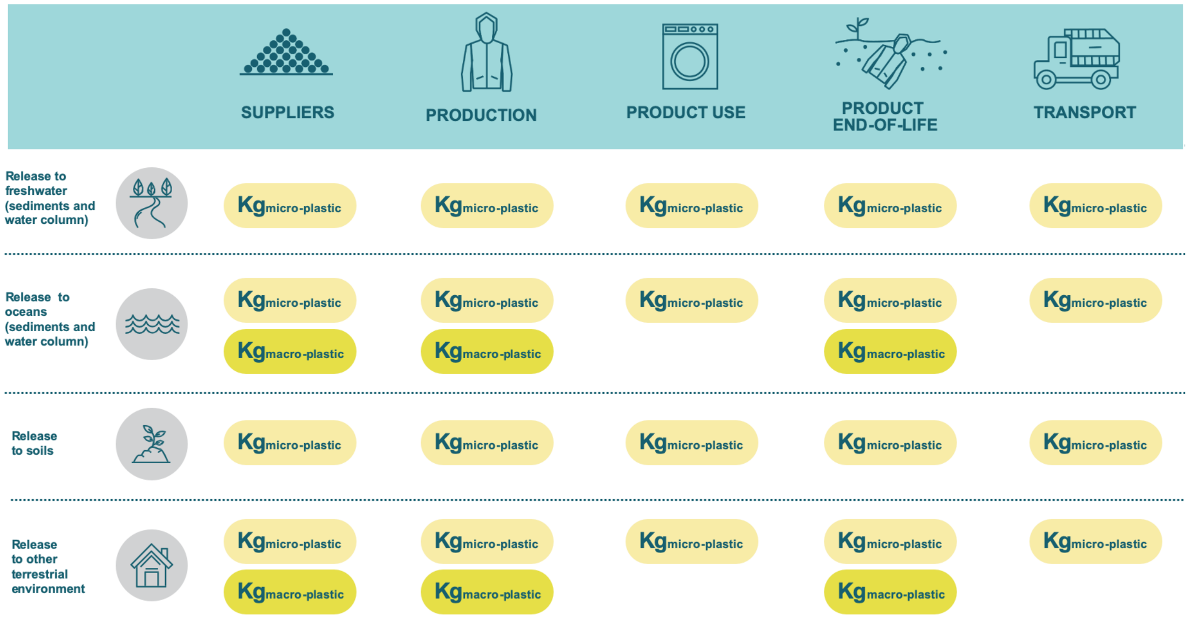

Figure 3.8 : Possible macro- and microplastic leakage during each life cycle stage and final release compartment

3.9.4 Country perspective

The country perspective shows plastic leakage hotspots as well as the plastic leakage intensity per country in the event the value chain is spread across several countries. It can be centered on one specific life cycle stage or on all. Plastic leakage results may be aggregated as a single score or per life cycle compartment. A finer or larger geographical unit (e.g., city, region, continent) can be used for reference if appropriate.

Figure 3.9 shows an example of country perspective for the leakage occurring at the end-of-life in the Arla Foods case study. This end-of-life leakage is influenced by the quantity of packaging distributed to each country as well as its loss rate (driven by littering rate and mismanaged waste rate, which depend on country waste collection and treatment infrastructure), its release rate (driven by the packaging size and residual value) and its redistribution rate.

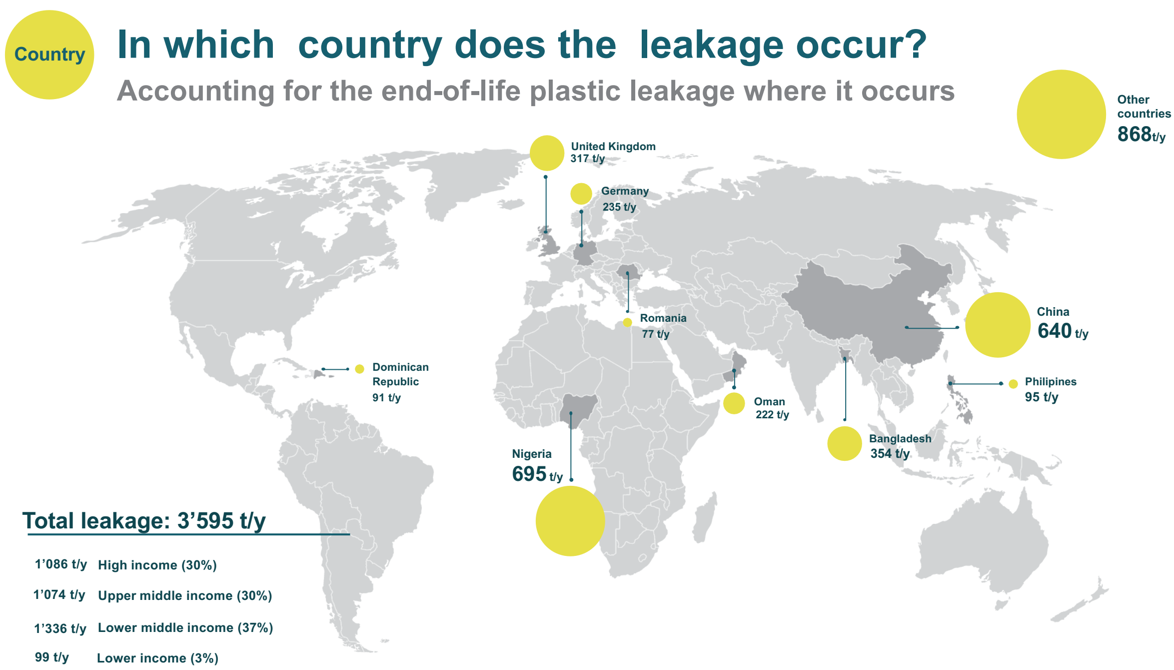

Figure 3.9 : Example of a country perspective within a plastic leakage assessment from the Arla Foods case study (available in at the end of this guidance document)

3.9.5 Market perspective

The market perspective offers an alternative regionalized indicator that can be complementary to the country perspective in the event the leakage occurs in a different location than where the product is consumed. For example, textile products may have a second life in lower income countries, where they are ultimately disposed. This means that the leakage in lower income countries is due to the initial consumption in higher income countries, which can be considered responsible for this leakage. In this way, the market perspective attributes the leakage upstream and downstream of the consumer **to the market that initiated the demand for the product**. For instance, leakage occurring during all life cycle stages except use and end-of-life, if disposed of by the consumer, are allocated according to the distribution markets.

Figure 3.10 shows an example of market perspective for leakage occurring at the second end-of-life in the Sympatex Technologies case study, where highlighted countries represent the markets that initiated the demand for the sports jacket.

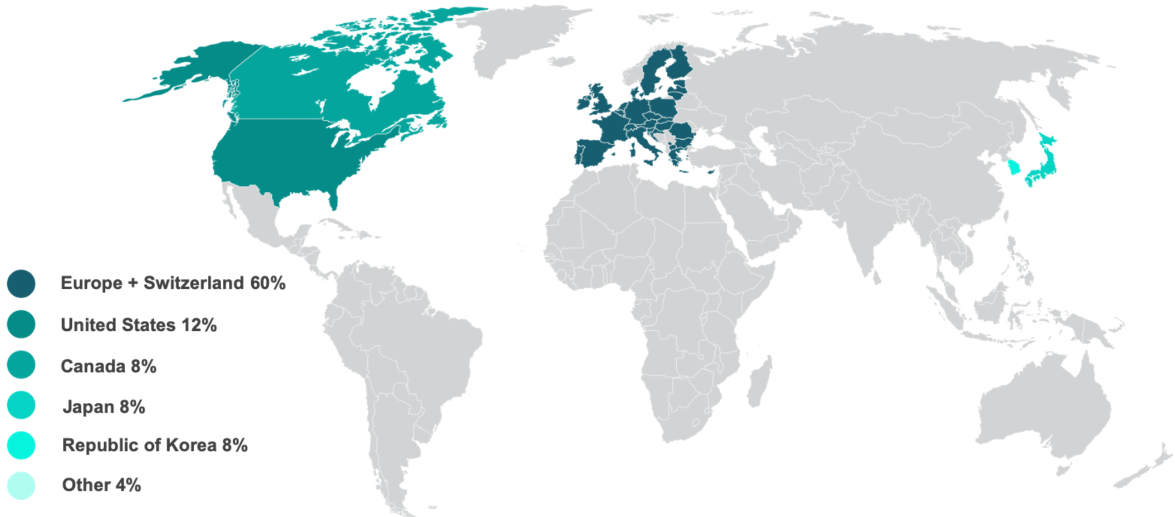

Figure 3.10 : Example of market perspective on a plastic leakage assessment (available in the case studies)

3.9.6 Product and polymer perspective

In the case of a corporate footprint or product made of different polymers, the plastic leakage assessment should include an inventory of different product and polymer types leaking into the environment.

These disaggregated metrics shall include the partitioning of plastics among different environmental compartments and countries as well as a detailed inventory of different products and polymers. These disaggregated results can be used for internal reporting as well as impact assessment. Indeed, in anticipation of methods that will quantify the impact of micro- and macroplastic leakage on ecosystems and human health that will be developed in coming years, the results of this methodology ought to be disaggregated in alignment with those forthcoming methods.

Figure 3.11 shows an example of leakage perspective per polymer for the Arla Foods case study.

Leakage in t/y	Nigeria	China	Bangladesh	United Kingdom	Germany	Oman
LDPE		431		99	46	184
Laminate	694	33	354	110	50	
PP	1	81		46	101	11
HDPE		59		25	8	9
PET		5		7	1	13
PS		25		11	6	4

Figure 3.11: Example of polymer perspective on a plastic leakage assessment

3.9.7 Fate perspective

In addition, plastic leakage may be accounted for as an equivalent of plastic remaining after degradation at the end of one year, i.e., t+1 (fate time frame as defined in Figure 3.4), if data on plastic degradation are available. It can be expressed either as a single aggregated indicator or by several metrics reflecting different perspectives. It accounts for the life span of different plastic polymers in various compartments as discussed in section 3.7.

This has not been applied yet because the data available to characterize the degradation of the different polymers in different environmental compartments are still insufficient.

Goal and scope of a plastic leakage assessment

4

4.1 What are the key stages of the plastic leakage calculation?

The plastic leakage framework is inspired from and consistent with the conventional LCA framework, following ISO 14040 (ISO 2006a) and ISO 14044 (ISO 2006b) standards.

Figure 4.1 presents the general framework of a plastic leakage assessment that can be applied to companies or products. It starts with 1) the definition of the goal and scope of the plastic leakage assessment, including objective setting, the definition of system boundaries, functional unit, and reference flows. Then 2) the inventory of the plastic leakage can start, by evaluating micro- and macroplastics used and wasted during production, and use and waste stages of a product. Each loss and release rate is calculated based respectively on the activity and polymer as well as local infrastructure. Then 3) the impact assessment of the plastic leakage is partially addressed in these guidelines through the inclusion of plastics fate (plastic redistribution from the initial release compartment to the final release compartments, as well as fragmentation and/or degradation). The impacts of plastic leakage on ecosystems and human health should be evaluated through measures to be developed in coming years. Due to lack of data, these impacts are not included in this report. Finally, 4) interpretation should be performed at each stage of the assessment to ensure that results are consistent with the defined goal and scope. This phase ensures that conclusions are reached, limitations are explained, and recommendations are provided.

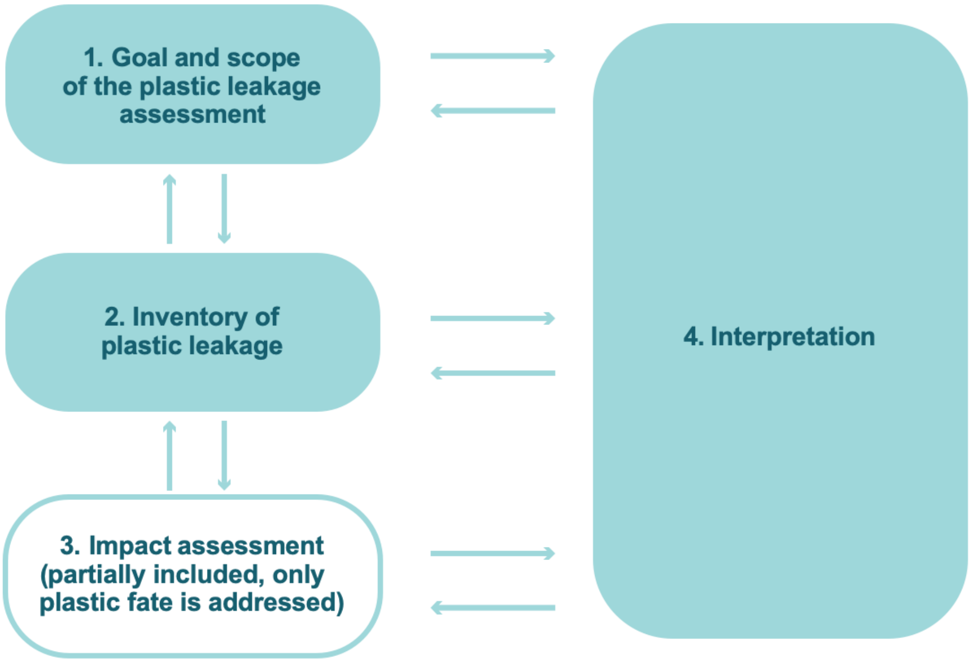

Figure 4.1 : General framework of the plastic leakage assessment and relation with the LCA framework as described in the ISO 14040/44 standards (Boucher et al. 2019). For "plastic fate" definition, refer to section 3.7.

These different steps are described in the following sections.

4.2 How to define the study objective?

Defining the study's objective is required to determine the level of precision and therefore the amount of effort to invest in collecting primary activity data, loss rates and release rates. A generic approach intended to compare leakages from different products or industries may rely on general and average data (such as the data provided in this report). A more specific approach, for example to target a specific product or industry or to design solutions within an industry, will require refining the emission factors in a way that identifies the drivers for progress in the output metric. Take for example performing the eco-design of a textile garment. One should consider a set of loss rates based on the parameters that yield meaningful distinctions, which are likely to include fiber type, yarn type, wash settings, geography and perhaps others. A key challenge here is that the loss or release rates may not be readily available and may require further research and testing to be documented.

4.3 What are the system boundaries and covered leakage routes?

System boundaries should be chosen in accordance with the objective of the study and should be carefully documented. All leakage sources occurring during all life cycle stages should be included. Leakage sources that cannot be assessed due to lack of data should be documented. A list of possible sources of plastics leakage is presented in Table 4-1. The sources covered by these guidelines are highlighted; they are related to plastic products and packaging (for macroplastics), textile washing, tire abrasion and plastic pellet production (for microplastics). Specific evaluations that involve a potentially important additional leakage route should consider other leakage pathways, such as fishing devices for seafood or agricultural plastic for agricultural products.

Table 4-1: Main sources of macroplastics and microplastics. Highlighted in blue are the sources included in the guidelines (Lassen et al. 2015).

Sources of macroplastics	Plastic packaging end-of-life
	Plastic product end-of-life
	Fishing devices lost at sea
	Agricultural plastic leaked during use
Sources of microplastics	Textile washing
	Tire abrasion
	Plastic pellet production
	Cosmetics
	Construction industry
	Turf and artificial grass
	Road markings
	Building paints
	Marine coatings

System boundaries should cover the different scopes defined in section 4.1 and results should be expressed in accordance with section 3.9.

4.4 How to define a functional unit?

Defining a functional unit (FU) is a key step of any environmental assessment activity. It represents the unit by which reference flows (see Table 4-2) are tallied and results are expressed. A plastic leakage assessment functional unit should be defined for a product or corporate assessment. A product's functional unit should be defined case by case in a product LCA to reflect proper understanding of the product function. We refer the reader here to conventional LCA textbooks. Corporate assessments are generally based on a one-year period of activity. This time scale is not related to the release and fate time horizon defined in section 3.8, given that the functional unit defines the time period during which plastic leakages shall be considered, while the release and fate times addressed in the methodology start after this initial leakage.

Table 4-2 presents examples of functional units.

Table 4-2 : Examples of functional units

Type of assessment	Examples of functional unit	Reference
Product LCA	To provide 100 ml of water from sealed containers ready to be consumed	Packed water Product Environmental Footprint Category Rule (PEFCR)
	One T-shirt ready-to-wear and cleaned, once a week, for one year	T-shirt Product Environmental Footprint Category Rule (PEFCR)
Corporate LCA	One year of a company activity	Retail Organization Environmental Footprint Category Rule (OEFSR)

4.5 Which data sources can be used and what are the data quality requirements?

All foreground[7] technosphere data should be primary data collected over the most recent calendar year of operation or measurement year. **Primary data** should include the location of the manufacturer, the quantity and source location of all plastic losses occurring during a product life cycle or a company activity as well as the distance traveled at each life cycle stage.

Secondary data sources may be used as proxies or substitutes and derived from peer reviewed literature only when primary data are unreliable or not available. Generic datasets may be used for processes the manufacturer cannot influence, e.g., processes dealing with production of input commodities, raw material extraction, electricity generation, or processes referring to product use and end-of-life. As a matter of principle, consistent and equivalent generic data shall be used for background processes to ensure that results are comparable.

Requirements for the use of **primary and secondary data** are specified in the sectoral guidance for each product considered in these guidelines.

Data quality requirements shall be treated according to the following criteria and shall be documented in the report according to ISO 14044[8] . The following guidelines are derived from the PEF requirements (European Commission 2017).

- Time representativeness:
  - The foreground data should be less than three years old for primary data, i.e., should have been collected over the most recent calendar year of operation or measurement year where the start date is not more than three years prior. The measurement dates should be disclosed in the study.
  - Primary data should be based on one year of typically averaged data; deviations should be justified.

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[7] According to PEF Guide (2013), a foreground process is a core process in the product life cycle for which direct access to information is available. This is in contrast to background process, i.e., a process in the product life cycle for which no direct access to information is possible.

[8] For further insight on data quality, refer to:

a. Weidema, B. and M. Suhr Wesnaes. Data quality management for life cycle inventories, an example of using data quality indicators. Journal of Cleaner Production, 1996 , Vol. 4, no. 3-4, p. 167-174

b. University of Leiden. Quality Assessment for LCA, CML Report 152, http://www.leidenuniv.nl/cml/ssp/publications/quality.pdf

- Geographical coverage: primary data should be gathered from the sites where specific processes were carried out. When using secondary data, regional datasets should be preferred to country specific data whenever available.
- Technology coverage: where generic data are used, technological equivalence (specific technology or technology mix) should be observed, i.e., should adhere to “Data deriving from the same chemical and physical processes or at least the same technology coverage (nature of the technology mix, e.g., weighted average of the actual process mix, best available technology or worst operating unit)”.
- The representativeness of the datasets with respect to time, geographical coverage, and technology should be documented, and deviations from the actual time, location, and technology relevant to the product should be disclosed.
- Data sources: all data sources should be specified. Data taken from literature should be identified as such in the report, including the source.
- Data gaps: the treatment of missing data and use of data models should be documented. When data from comparable processes are used to compensate for gaps, the technological equivalence should be documented.

Inventory of plastic leakage

5

An inventory of plastic leakage at product or corporate level involves two steps:

1) **Map the macro- and microplastics leakage**: the nature of the leakage and the country where it occurs are identified.
2) **Collect data**: primary and secondary data are defined. Secondary data are provided in the excel file PLP_Sectorial_Guidances_Generic_data. When no primary data are available, secondary data shall be used.

These steps are described in the following sections.

5.1 Map leakage over life cycle

When assessing plastic leakage, the first step is to map the leakage over the life cycle of a company or product. The framework of the system boundaries presented in Figure 4.1 should be followed. For each scope it will be necessary to identify:

- The nature of leakage
- The country where the leakage occurs

The identified sources of macro- and microplastics are listed in Table 4-1.

In Table 5-1 and Table 5-2, examples of plastic leakage maps are shown, and guidelines for calculations are provided.

Table 5-1 : Macro- and microplastic leakage for a typical company assessment

Life cycle steps	Nature of plastic leakage	Related section in the guidelines
SUPPLIERS	Microplastics from pellet production	Section 9: Inventory of microplastic leakage from plastic production
	Macroplastics from plastic used at farms (for ingredient production)	Not included in these guidelines
PRODUCTION	Macroplastics from packaging production	Section 6: Inventory of macroplastic leakage from plastic waste
	Microplastics from product manufacturing (e.g., textile fabric preparation and assembly) The leakage of micro-beads from cosmetic manufacture is not covered in this report.	Section 7: Inventory of microplastic leakage from textiles
PRODUCT USE	Microplastics from textile washing The leakage of micro-beads from cosmetic application is not covered in this report.	Section 7: Inventory of microplastic leakage from textiles
PRODUCT END-OF-LIFE	Microplastics from landfills	Not included in these guidelines
	Macroplastics from products and packaging end-of-life	Section 6: Inventory of macroplastic leakage from plastic waste
TRANSPORT	Microplastics from tire abrasion	Section 8: Inventory of microplastic leakage from tire abrasion during transport
	Microplastics from road markings	Not included in these guidelines

Table 5-2: Macro- and microplastic leakage for a 100 ml water bottle assessment

Life cycle stages	Nature of plastic leakage	Related section in the guidelines
SUPPLIERS	Microplastics from pellets	Section 9: Inventory of microplastic leakage from plastic production
PRODUCTION	Macroplastics from packaging production	Section 6: Inventory of macroplastic leakage from plastic waste
PRODUCT USE	Not applicable	-
PRODUCT END-OF-LIFE	Microplastics from landfills	Not included in these guidelines
	Macroplastics from packaging end-of-life	Section 6: Inventory of macroplastic leakage from plastic waste
TRANSPORT	Microplastics from tire abrasion	Section 8: Inventory of microplastic leakage from tire abrasion during transport
	Microplastics from road markings	Not included in these guidelines

5.2 Collect primary data and identify sources for secondary data

Once the sources and countries of leakage are identified, it is possible to proceed with collecting primary data and identifying secondary data.

This document provides recommended sources of secondary generic data that can be used as default where no specific primary data are available. The difference between primary and secondary data is defined below and in section 4.5:

- Primary industrial data are collected specifically for a defined study; this includes direct activity data such as the amount and type of plastic packaging used on an industrial site, transport distances, and the use of synthetic textiles.
- Secondary generic data can be applied as default for key assumptions such as regionalized macroplastic waste management pathways or plastic release rates. Industrial activity default data can also be used when no primary information is available, such as textile wash frequency, load and temperature.

In general, only when primary data are not available may secondary data sources be used. For more information, please refer to section 4.5.

Figure 5.1 presents different stages where primary or secondary data can be used.

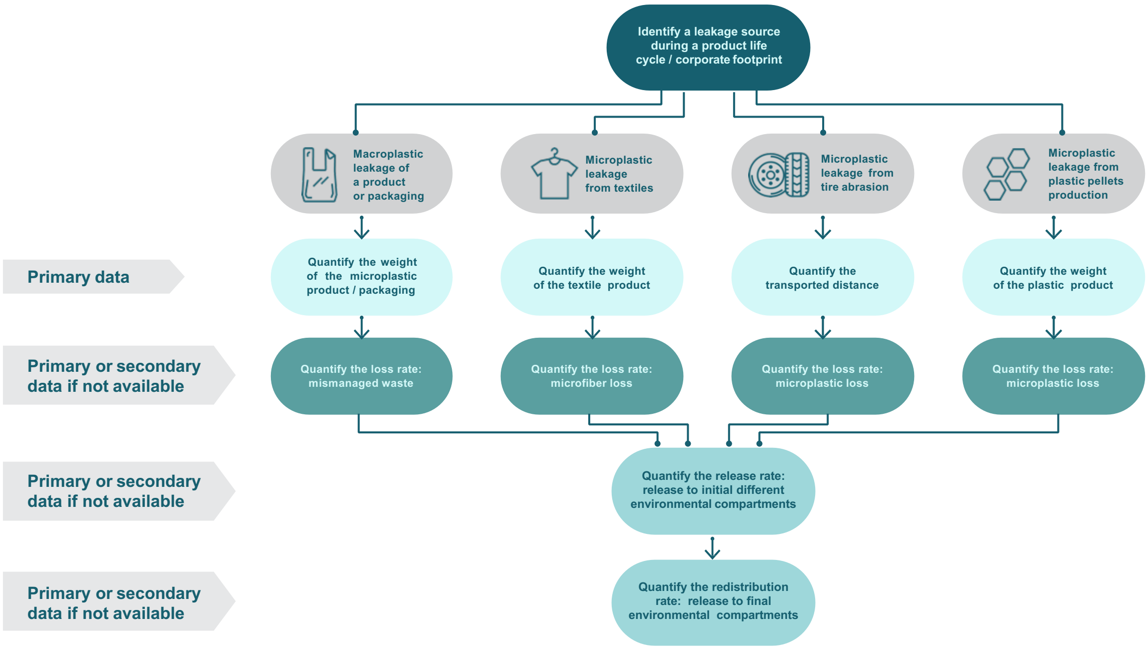


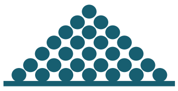
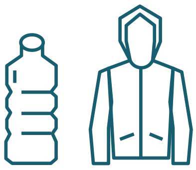
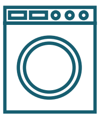
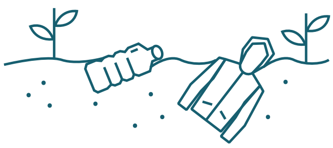
Figure 5.1: Use of primary and secondary data to support product and corporate plastic footprint

Table 5-3 provides a data quality assessment on the secondary data (loss and release rates) provided in the guidelines. These data quality ratings are provided to help the user understand the quality of the secondary data proposed by this guidance, to enable the user to improve data quality where it is weak and/or most consequential to the results. The different levels of data quality are defined as follows:

- High quality: several sources of data are available, the data fall within a relatively narrow range, the mechanism is well understood
- Average quality: only one or few sources of data, or wide range of values are reported
- Low quality: lack of data and/or mechanism is not well understood.

Whenever relevant data and ranges are available, sensitivity analyses should be performed to test how results may vary given different input data.

Table 5-3 : Data quality assessment for secondary data provided in the guidelines

Life cycle stages	Nature of plastic leakage	Related section in the guidelines	Data quality
 **Suppliers**	Microplastics from pellet production	Section 9: Inventory of microplastic leakage from plastic production	low
	Macroplastics from agricultural plastic	Not included in these guidelines	low
 **Production** **Company owned**	Macroplastics from product and packaging production	Section 6: Inventory of macroplastic leakage from plastic waste	average
 **Product use**	Microplastics from textile washing	Section 7: Inventory of microplastic leakage from textiles	good
 **Product end-of-Life**	Microplastics from landfills	Not included in these guidelines	low
	Macroplastics from product and packaging end-of-life	Section 6: Inventory of macroplastic leakage from plastic waste	average
 **Transport**	Microplastics from tire abrasion	Section 8: Inventory of microplastic leakage from tire abrasion during transport	good
	Microplastics from road marking	Not included in these guidelines	low

Inventory of macroplastic leakage from plastic waste

6

6.1 System map for the leakage of macroplastics to the environment

The route covers macroplastic losses during a product life cycle or various value stages of corporate activities. These losses can occur at the production stage (e.g., agricultural plastic lost on field or plastic scrap lost at the manufacturing facility) or during the use stage of a plastic product (e.g., fishing devices lost during fishing activities) or at plastic packaging or product end-of-life (e.g., a plastic bag littered in the street).

Figure 6.1 represents the general methodological principles to account for plastic leakage to the environment applied to macroplastics.

For each leakage pathway, three main calculation steps are foreseen.

The **loss,** applied as a loss rate (LR), is a measure of the quantity of plastic that leaves a properly managed product or waste management system. In the PLP guidance, for macroplastics, we consider three potential sources of loss:

- Plastic packaging waste
- Plastic products waste
- Other sources such as agricultural waste, fishing devices or infrastructure (construction waste)

Macroplastics can then follow different **transfer pathways** before release. In the PLP guidance, we consider four potential transfer pathways:

- Wastewater treatment pathway
- Direct pathway (e.g., fishing devices lost at sea)
- Uncollected waste pathway, including littered waste that is not collected
- Poorly managed waste pathway, corresponding to the waste lost from inadequate waste management

Uncollected or poorly managed waste can be collected by **waste pickers** that perform informal waste collection; in this case, the waste presumably returns to a properly managed waste pathway.

In the rest of the guidance, **mismanaged waste** refers to any waste either directly discarded in water, uncollected, or poorly managed. These pathways are further described in section 6.2. To these losses can be attributed a probability of being transferred to a natural compartment, measured through the release rate.

The **release**, applied as a release rate ($RelR$), is a measure of the plastic transported towards an initial environmental compartment. In the PLP guidance, for macroplastics, we consider three potential initial release compartments:

- Freshwater
- Ocean
- Other terrestrial environment (any compartment other than freshwater, ocean, air and soil, mainly on soil surface such as dumpsites, trees, roads and road sides, etc.)

The release rate is the fraction of loss that is released to a given initial release compartment by way of a specific transfer pathway.

The **redistribution**, applied as a redistribution rate ($RedR$), is a measure of the plastic redistributed towards a final environmental compartment. The redistribution rate is the fraction of the release that is redistributed in different environmental compartments.

For example, plastic packaging or a plastic product littered in the street follows an uncollected waste pathway, then may be transferred to a river by rain, and then ultimately redistributed to the ocean.

Key parameters are shown in Figure 6.1 and defined in Table 6-1.

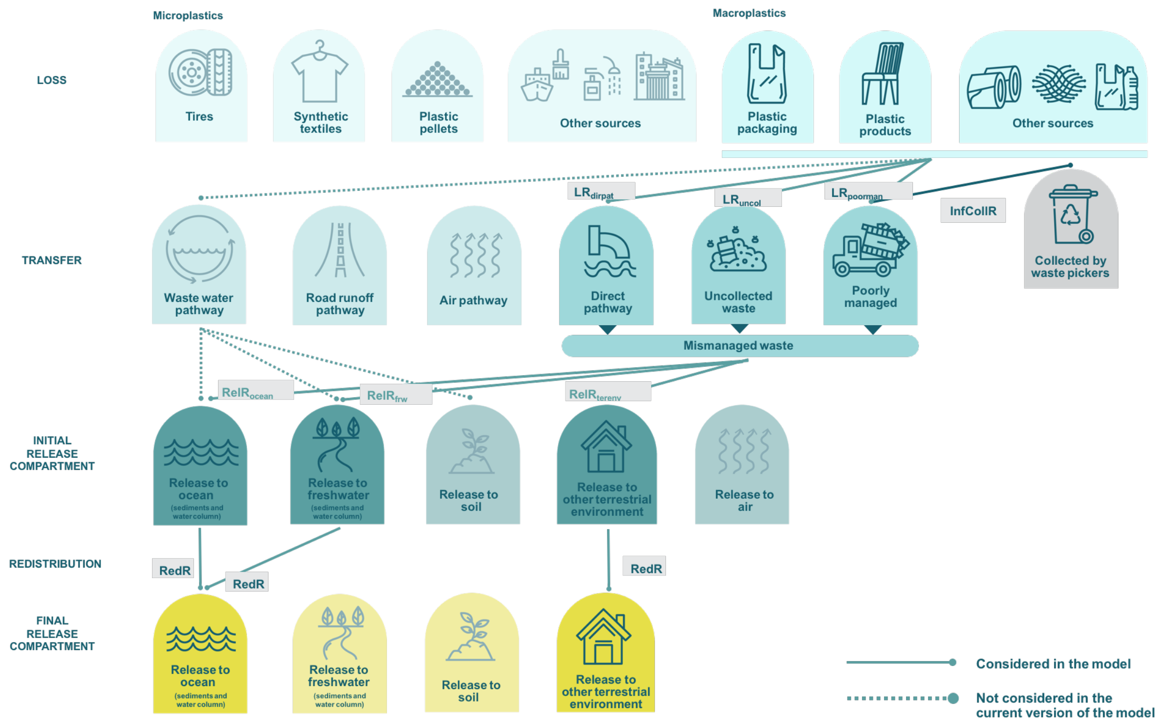


Figure 6.1: Losses, transfer pathways and plastic release compartments for macroplastics

6.2 Loss rate: wastewater treatment, direct, uncollected waste and poorly managed waste pathways

Knowing the quantity of waste that is not adequately treated is one of the first steps to estimating quantities of macroplastics that are prone to be lost at plastic packaging and product use and end-of-life.

Figure 6.2 presents the different transfer pathways in greater detail.

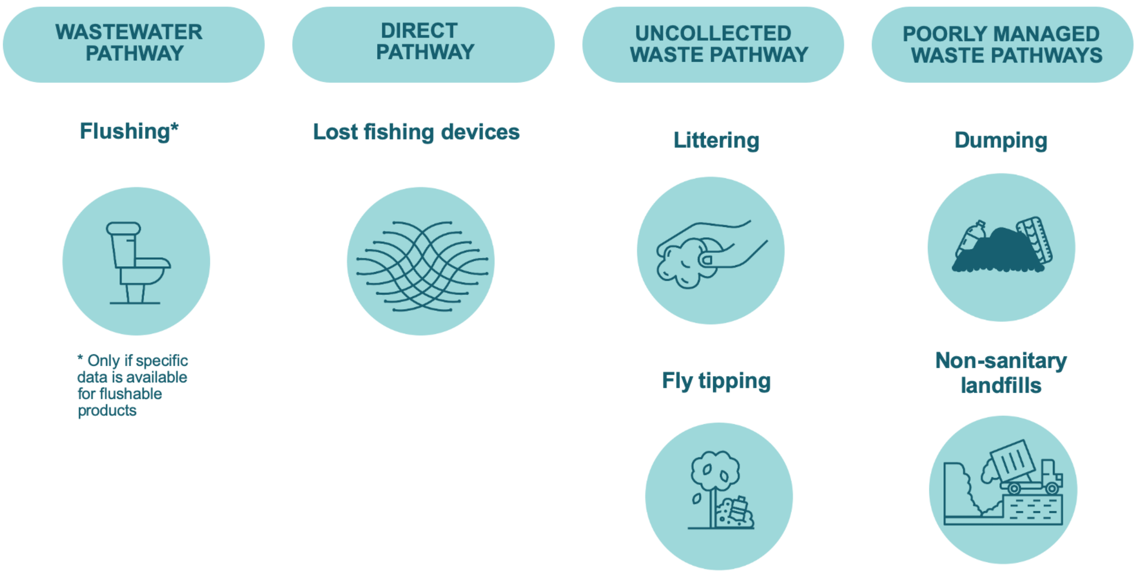


Figure 6.2: Macroplastic transfer pathways

Flushable products following the **wastewater treatment pathway** are not considered in this methodology due to lack of data, i.e., no generic loss or release rates are available. This pathway should, however, be covered if the study addresses the plastic leakage of a product disposed of by flushing (e.g., wipes, swabs, sanitary products) or a company producing this type of product. Specific data should then be used to cover this pathway. Indeed, when waste is disposed of in a sewage system, larger items would normally be captured by wastewater treatment where facilities exist. However, materials can bypass systems and enter waterways when rain levels exceed sewer volumes or sewage treatment facility handling capacities.

The **direct pathway** (LR_{dirpat}) includes fishing apparatuses lost in freshwater and oceans from both recreational and commercial fishermen (e.g., nets, fishing line and bait boxes), shipping and tourism.

Uncollected (LR_{uncol}) and **poorly managed waste** ($LR_{poorman}$) can be grouped in the category of mismanaged waste. Jambeck et al. (2015) define mismanaged waste as "material that is either littered or inadequately disposed. Inadequately disposed waste is not formally managed and includes disposal in dumps or open, uncontrolled landfills, where it is not fully contained". We broaden this definition to include all waste whose collection or disposal route creates the potential to be lost and released into the environment, that is, waste that is not appropriately transported, collected or stored.

Uncollected waste (LR_{uncol}) includes:

- **Littering**: Littering is the improper disposal of typically small, one-off items, such as throwing on the ground a cigarette, snack pouch, or a disposable cup. Most of the time these items fall first on the road or sidewalk. They may or may not be collected by municipal street cleaning. Littering is common in all parts of the world, irrespective of income level (Velis et al. 2017). It is either part of day-to-day activities or a result of recreational activities (e.g., tourism or major public events). Parameters that can influence littering are presented in Figure 6.3.
- **Dumping/fly tipping**: Fly tipping is the deliberate disposal of larger quantities of litter in the environment outside of official waste collection and treatment locations. The waste is not collected through an official waste collection system and is typically discarded by household members themselves. This could be anything from a single bag of rubbish to a large sofa or broken refrigerator, e.g., accumulating on the road side, in remote places or being deposited directly into water in nearby water bodies and settlements. The degree of uncontrolled dumping of waste by households varies substantially in countries, cities and towns. It is a critical issue in low and middle-income countries where waste collection systems may be inadequate, leaving households no better option than to dispose of waste by dumping in a location within or close to their community (Velis et al. 2017).

Poorly managed waste ($LR_{poorman}$) includes:

- **Dumping:** In low-income countries, collected waste can end up in an open dump, which is prone to pollute nearby aquifers, water bodies and settlements.
- **Non-sanitary landfills**: In transition countries, landfills planned as controlled engineered sites can end up being mismanaged (e.g., light plastic waste may be blown away by wind, or carried away by runoff) (Velis et al. 2017).

If a greater share of waste was managed well, i.e., formally collected and treated in sanitary landfills, incineration and recycling facilities, it would have a significant impact in reducing behaviorally and structurally mismanaged waste. According to Ocean Conservancy, improving the current waste management system to increase collection and **plug post-collection** leakage could reduce macroplastic leakage by nearly 50 percent (McKinsey Center and Ocean Conservancy 2015). Overall, uncollected and collected waste appear to account for 75% and 25% respectively of the land-based macroplastic leakage (McKinsey Center and Ocean Conservancy 2015).

Burned waste is not considered in a plastic leakage inventory given that it does not contribute to macroplastic debris that can leak into the environment (although it can induce microplastics formation). However, burned waste without proper fume treatment induces potentially toxic emissions and greenhouse gases that should be reflected within other LCA impact categories.

A portion of uncollected or poorly managed waste is collected by **waste pickers,** and it is presumed this waste is not released in the environment as it will likely be recycled or reused.

6.3 Initial release rate

Not all lost waste translates to leaks into the environment. The fraction of lost or mismanaged waste that does leak into the environment is defined as release rate.

Several factors can influence the release rate. Figure 6.3 presents a preliminary list of these factors (ISWA 2018). We can expect factors such as cultural and economic background (e.g., littering habit, number of bins in public places, tourism rate), climatic conditions (e.g., effect of rain or wind on dispersal of waste from dumpsites), geographic specificities (e.g., distance to shore and waterways) as well as waste characteristics (e.g., residual value of waste) to have substantial influence on these release rates. Due to the lack of quantitative studies and models on this topic, only waste residual value and size are considered as parameters of influence to calculate release rates in this guidance.

In accordance with Ocean Conservancy (McKinsey Center and Ocean Conservancy 2015), waste residual value is assumed in this project to be dependent on the price at secondary dealers and time to collect, combined with a qualitative function of homogeneity and likelihood of rejection by secondary dealers.

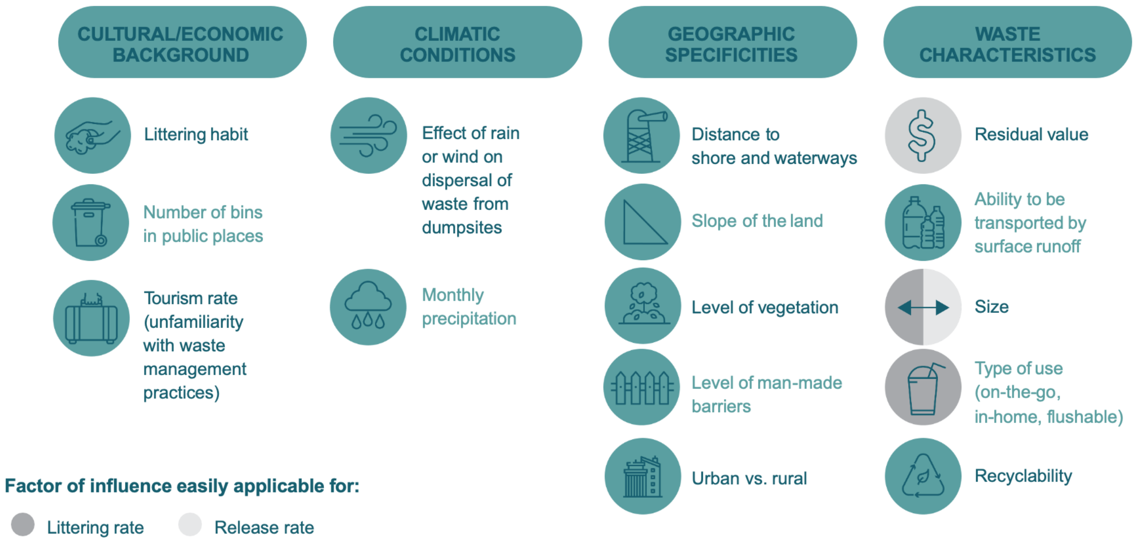


Figure 6.3: Parameters influencing littering and release rates

Given how complex it is to model these regionalized parameters and understand how they influence the release rate, the release mechanisms are as yet poorly understood; therefore release rates provide indications rather than estimates. For example, a commonly used value for release rate into the ocean to date is 25%, published by Jambeck et al. (2015) (the publication presents three possible values of 15%, 25% and 40%).

Field studies and a more in-depth understanding of the release pathways are needed to fine-tune these numbers.

6.4 Redistribution rate

In the case of macroplastics, we consider that all plastic released to freshwater as well as the ocean ultimately reach the ocean and that plastics released to terrestrial environments remain in the terrestrial environments.

6.5 Calculation routes for the leakage of macroplastics to the environment

6.5.1 Data collection (reference flows)

The first step to start a plastic leakage analysis is to collect data on the mass of plastic waste (MPW) differentiated by different types of polymers (if possible) including regionalized information on macroplastics' end-of-life. Data should be collected for all reference flows, following the logic of scopes illustrated in Figure 6.4.

This macroplastic waste data for a product or corporate footprint serves as a starting point to apply the loss/release/redistribution sequence as described in the next sections. Macroplastic losses can occur at supplier, production and end-of-life stages. The product end-of-life is strongly influenced by consumer behavior during the use stage (e.g., littering).

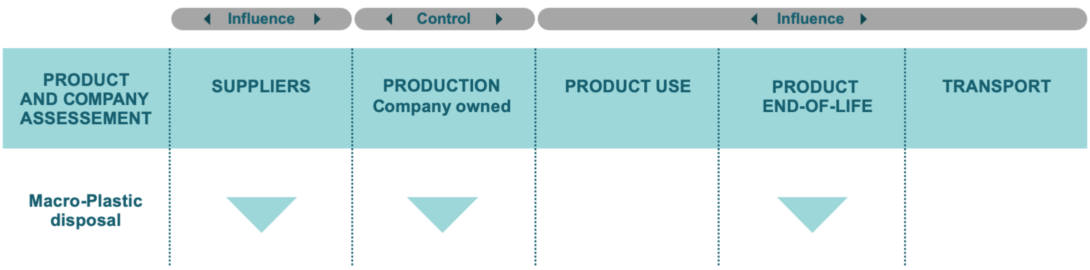


Figure 6.4: Macroplastic loss during a product or corporate life cycle

6.5.2 Calculation parameters

Table 6-1 presents the parameters used throughout the guidance in case primary specific data are not available. These generic values should be used to estimate the product or corporate leakage of a plastic packaging or product. These values should be updated and improved as the state of the art evolves on this topic. All calculation parameters are summarized in the file PLP_Sectorial_Guidances_Generic_data.

Table 6-1: Parameters used to calculate the amount of plastic leaked to the ocean

Abbreviation	Description	Unit	Generic Value If No Data Available	Reference
MPW	Mass of plastic waste	kg	Collected data for a plastic leakage study	
LR	Total loss rate	% of waste	Calculated per country	
LR_{dirpat}	Loss rate for the direct pathway	% of waste	Values per country	World Bank (2018)
LR_{uncol}	Loss rate for the uncollected waste pathway	% of waste	Calculated per country	
$LR_{poorman}$	Loss rate for the poorly managed waste pathway	% of waste	Calculated per country	
$Littering$	Littering rate	% of waste	Littering rate matrix based on size and use	
$Fly\ tipping$	Fly tipping rate	% of waste	Calculated per country	
$Dumping$	Dumping rate	% of waste	Calculated per country	
$Landfill$	Landfill rate	% of waste	Calculated per country	
$Unspecified\ landfills$	Unspecified landfill rates per country	% of waste	Values per country	World Bank (2018)
$Open\ dump$	Open dump rates per country	% of waste	Values per country	World Bank (2018)
$Unaccounted\ for$	Rates for waste that is not included in official statistics	% of waste	Values per country	World Bank (2018)
$RelR_{ocean}$	Release rate to the ocean	% of lost waste	Release rate matrix based on size and residual value	Expert estimation
$RelR_{frw}$	Release rate to freshwater	% of lost waste		Expert estimation
$RelR_{terenv}$	Release rate to terrestrial environment	% of lost waste		Expert estimation
$InfCollR$	Informal collection rate for mismanaged waste by waste pickers	% of lost waste	Calculated	
$RedR_{ocean\_ocean}$	Redistribution rate from the ocean to the ocean	% of released waste	100%	Expert estimation
$RedR_{frw\_ocean}$	Redistribution rate from freshwater to the ocean	% of released waste	100%	Expert estimation
$RedR_{terenv\_terenv}$	Redistribution rate from other terrestrial environment to other terrestrial environment	% of released waste	100%	Expert estimation
$Leak\_macro$	Macroplastic leakage	kg	Calculated	

6.5.3 Calculation rules for loss rates

The loss rate represents the mass of waste lost as a percentage of the mass of plastic waste (MPW) generated.

The equations to calculate the global loss rates $LR_{dirpath}$, LR_{uncol} and $LR_{poorman}$ for packaging and non-packaging waste are presented below in Figure 6.5. For both packaging and non-packaging waste, LR includes plastics directly disposed of in waterways and oceans, non-collected waste and collected waste that is poorly managed (e.g., littered waste in the case of packaging). These loss rates can be any value from 0 to 100%, but are not expected to be 100% in most cases.

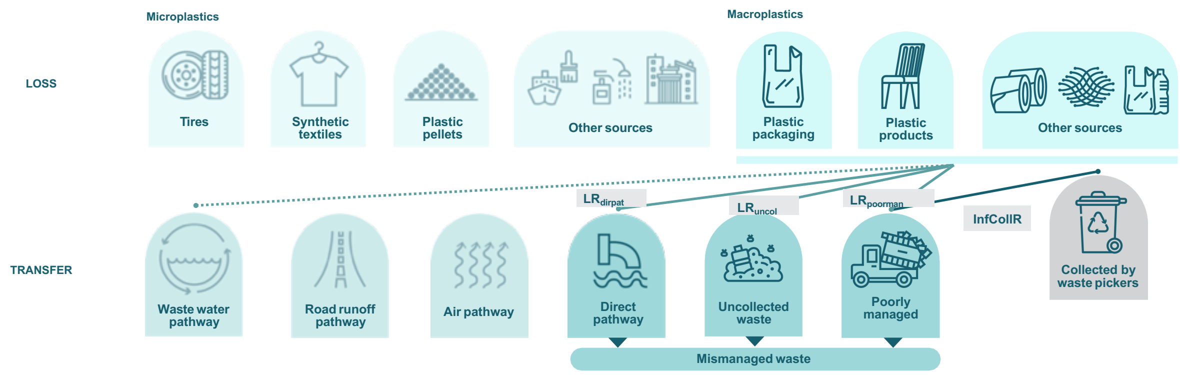


Figure 6.5: Loss rates for macroplastics

$LR_{dirpath}$ represents the loss rate for plastic packaging and products transferred through a direct pathway. This loss rate is regionalized and, unless specific data are available, one can rely on country statistics from the World Bank (Kaza et al. 2018) from the category "Discharge in waterways". This category includes both lost fishing apparatuses and waste disposed directly in waterways or oceans.

LR_{uncol} represents the loss rate for plastic packaging and products transferred through uncollected waste, i.e., littering and fly tipping.

$LR_{poorman}$ represents loss rate for plastic packaging and products transferred through poorly managed waste, i.e., dumping and non-sanitary landfills.

$$LR = LR_{dirpath} + LR_{uncol} + LR_{poorman}$$

$$\begin{aligned} LR = Littering + (1 - Littering) * (LR1 + +Fly\ tipping + Dumping + Landfill) \\ = Littering + (1 - Littering) * (\text{Unspecified landfills} + \text{ Open dump} \\ + \text{ Unaccounted for}) \end{aligned}$$

Jambeck et al. (2015) estimate the **littering rate** $Littering$ to be 2% for plastic land sources of packaging, single-use plastic or any on-the-go plastic waste (Jambeck et al. 2015), and 0% for more durable types of plastic waste. Although several parameters influence the littering matrix such as cultural behavior and the littering collection infrastructure (e.g., number of bins in public places, municipal waste collection), we recommend a preliminary estimate of packaging littering rates based on the packaging type and size. Table 6-2 presents these preliminary estimates. Durable goods made of plastic (e.g., plastic parts of furniture such as tables or chairs, as well as infrastructure such as windows) are assumed not to be littered.

Table 6-2: Littering rate matrix

LITTERING RATE $Littering$	In-home (non-flushable)		In-home (flushable)		On-the-go	
Small or detachable (< 5cm)	0%		5%	E.g.,cotton swabs	5%	E.g.,wrapper, lid
Medium Size (5-25cm)	0%	E.g.,PET bottle	0%	E.g.,wet wipes	2%	E.g.,cup
Large Size (>25cm)	0%		0%		1%	E.g.,plastic shopping bag

The **fly tipping, dumping** and **landfill rates** apply to the share of waste that has not been littered. Unless specific data are available, we suggest using country level release rates based on Kaza et al (2018) to cover $Flytipping + Dumping + Landfill$. When using data from this report, it can be assumed that plastics are treated as conventional municipal solid waste. Table 6-3 suggests an approach to calculate mismanaged waste based on end-of-life statistics and the country's level of development, classified as either high income, upper middle income, low middle income or low income by Kaza et al (2018). If the waste is disposed in an "unspecified landfill", it is considered to be mismanaged unless the "unspecified landfill" is located in a high income country. Based on this approach, "unspecified landfill" (except in high income countries), "open dumps" and "unaccounted for" can be considered to include fly tipping, dumping and non-sanitary landfills. $LR_{dirpath}$, LR_{uncol} and $LR_{poorman}$ are thus calculated to encompass mismanaged waste in Table 6-3.

Table 6-3: Approach to correlate country wealth level to level of waste management (Kaza et al (2018))

	High Income	***Upper Middle Income***	***Low Middle Income***	***Low Income***
Sanitary Landfill	Managed	Managed	Managed	Managed
Incineration	Managed	Managed	Managed	Managed
Unspecified Landfill	Managed	Mismanaged	Mismanaged	Mismanaged
Open Dump	Mismanaged	Mismanaged	Mismanaged	Mismanaged
Sanitary Landfill Gas Plant	Managed	Managed	Managed	Managed
Discharge in Waterways	Mismanaged	Mismanaged	Mismanaged	Mismanaged
Unaccounted For	Mismanaged	Mismanaged	Mismanaged	Mismanaged

Detailed loss rates per country are specified in the file *PLP_Sectorial_Guidances_Generic_data.*

Limitations – import/export of plastic waste

An important limitation to these loss rates arises from the fact that imports and exports of waste between countries are not considered. Indeed, the data used by default (What a Waste 2.0) considers that all waste is managed in the country of use and end of life, when in reality there is substantial inter-country trade of plastic waste, as shown on Figure 6.6. As a result, if the exported waste is not managed appropriately in the receiving county this may lead to additional leakage, which is important to reflect in the plastic leak model.

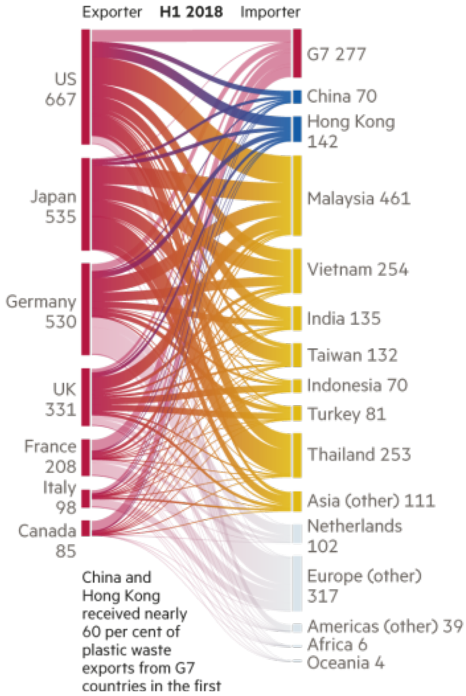


Figure 6.6 2018 G7 countries' exports of plastic, parings and scrap in metric tons, visualized in a Financial Times article based on the US Census Bureau, Japan e-Stat, Eurostat and Statistics Canada (Financial Times 2019)

Thus if data are available to quantify the movements and identify the destination and management practice for the exported waste, leakage shall be calculated for these plastic waste trade flows. In the absence of robust data, this could be done in the form of sensitivity analysis.

UN Comtrade database covers plastic waste flows and could help to estimate the quantities of plastic imported and exported by country. However, the final destination and mismanagement rate for imported materials are too hypothetical to be used. For a given country, it is likely inaccurate to attribute the same mismanagement rate to the imported waste (which is meant to have a high value for recycling) as used for domestic waste.

Given the high variability of mismanagement rates and the lack of generic data, we do not provide within this guidance any default assumptions for including leakage from plastic waste imported and exported. The authors acknowledge that import-export may be an important source of leakage and strongly recommend more research in this field to improve the modelling. This is a priority development to ensure the reliability of this methodology and ensure that it is used to identify relevant actions not omitting any hidden leakage.

6.5.4 Calculation rules for release rates

The release rate represents the percentage of waste released in a compartment compared to the mismanaged waste generated.

The equations to calculate the global release rates $RelR_{ocean}$, $RelR_{frw}$ and $RelR_{terenv}$ for packaging and non-packaging waste are presented in Figure 6.7 and below.

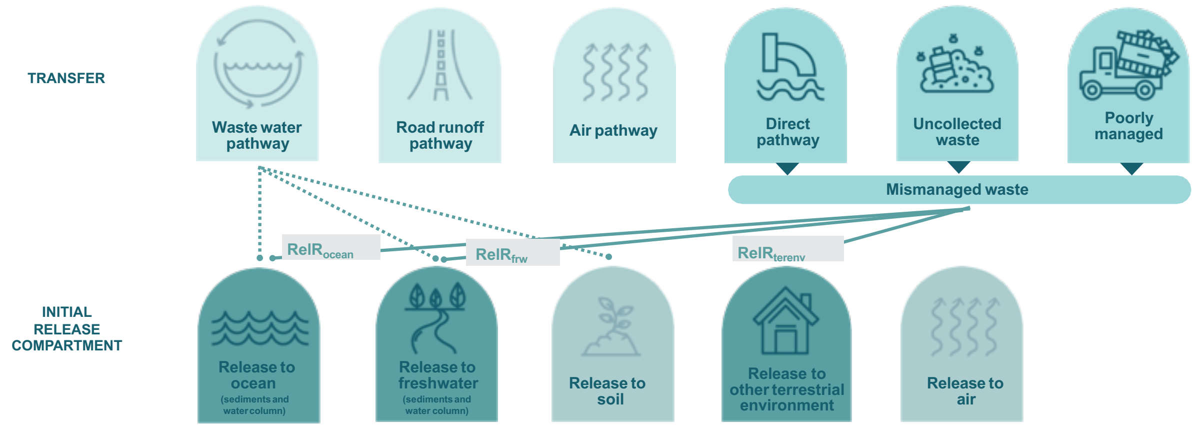


Figure 6.7: Release rates for macroplastics

$RelR_{ocean}$ represents the release of macroplastics to oceans, $RelR_{frw}$ the release to freshwater and $RelR_{terenv}$ to other terrestrial environments. In this guidance, we use a hybrid approach using key parameters that influence the variability of $RelR_{ocean}$, $RelR_{frw}$ and $RelR_{terenv}$ within an estimated range. The objective is to develop a method that allows a first, rough estimate without necessarily providing an accurate assessment of the actual leakage. This approach is based on the residual value and size of the plastic waste as presented in Table 6-4.

The concept of plastic waste **residual value** creates a link between the footprinting approach and circular economy concepts. Indeed, leakage in the environment depends on the residual value of a material and the likelihood it will be collected through the informal waste collection system, even if it has not been properly collected or treated through the formal waste collection and treatment pathway. About 20% of the municipal plastic-waste stream has enough value to incentivize collection by waste pickers (McKinsey Center and Ocean Conservancy 2015). More precisely, it is estimated that 80% of waste in landfills has low residual value (e.g., thin films, composites) and 20% has a relatively high residual value e.g., PET, HDPE (McKinsey Center and Ocean Conservancy 2015). Among plastics lost from the technosphere, it is estimated that 100% of low residual value materials leak into the environment, whereas less than 30% of high residual value plastics leak (more than 70% is assumed to be collected by waste pickers).

Definition: A product/polymer residual value can be assumed to be equal to its market price, or recalculated as a function of product homogeneity, time to collect, and resale price

We assume that all low- and medium-value plastics (e.g., polystyrene, LDPE) are released either to oceans or to terrestrial environments. On the contrary, we assume that high value plastics are collected by waste pickers and thus do not remain in the terrestrial environment. Only 15%, 10% and 1% of the lost high residual value plastics are assumed to be released to oceans for small-, medium- and large-size plastics, respectively.

These release rates are based on expert judgment supported by wider research. These rates should be updated as higher quality specific data become available.

Table 6-4: Release rate proposed approach, based on literature review and expert judgment

	Ocean ($RelR_{ocean}$) and freshwater ($RelR_{frw}$)	Terrestrial environment ($RelR_{terenv}$)	Ocean ($RelR_{ocean}$) and freshwater ($RelR_{frw}$)	Terrestrial environment ($RelR_{terenv}$)	Ocean ($RelR_{ocean}$) and freshwater ($RelR_{frw}$)	Terrestrial environment ($RelR_{terenv}$)
RELEASE RATE MATRIX	**Small Size (<5cm)**		**Medium Size (5-25cm)**		**Large Size (>25cm)**	
Low Value (others + composites, e.g.,wrapper, opercula, straw, balloon, plastic bag, cup, meal tray)	40%	60%	25%	75%	5%	95%
Medium Value (PP, PS, LDPE)	25%	75%	15%	85%	5%	95%
High Value (PET, HDPE)	15%	15%	10%	5%	1%	1%

As a point of comparison, Table 6-5 presents a list of release rates to ocean, obtained or extrapolated from literature. These data show that estimated release rates can be up to one order of magnitude smaller than the 25% default assumption often used in current reports.

Table 6-5: Release rates specified in the literature (explicit) or extrapolated from the cited study

Release Rates	Scope	Type	Source
15%/25%/40%	Global	explicit	(Jambeck et al., 2015)
10%	Global	explicit	(UN Environment, 2018)
3.2%	Global	extrapolated	(Lebreton et al. 2017)
2.9%	Global	extrapolated	(Schmidt et al., 2017)

The share of waste that is mismanaged but not released to the environment represents the share of waste collected by waste pickers, which is ultimately recycled or reused.

$$InfCollR = 1 - \left(RelR_{ocean} + RelR_{frw} + RelR_{terenv}\right)$$

6.5.5 Calculation rules for redistribution rates

The equation to calculate the redistribution rates $RedR$, for packaging and non-packaging waste is presented in

Figure 6.8 and below.

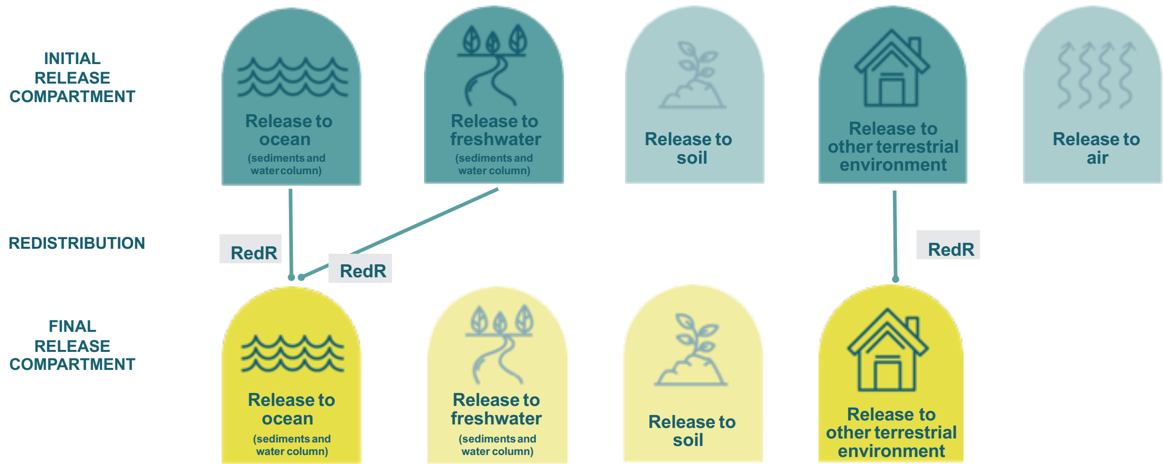


Figure 6.8: Redistribution rates for macroplastics

We consider that all plastics released to freshwater and oceans ultimately reach the ocean and that the plastics released to other terrestrial environments remain in the terrestrial environment. This is a preliminary assumption that should be refined as the methodology evolves, when further evidence becomes available to estimate the share of plastic carried to lakes and oceans, e.g., by wind or birds.

$$RedR = 100\%$$

6.5.6 Leakage

The leakage of macroplastics $Leak\_macro$ at life cycle stage X, in country Y and into the ocean or a terrestrial environment is ultimately calculated as the sum of mass of plastic waste (MPW) during a product life cycle or a corporate activity at $lifecyclestageX$, multiplied by the loss (LR) in $countryY$, the release ($RelR$) in different environmental compartments and the redistribution rates ($RedR$).

In the case of calculation of plastic leakage:

$$Leak\_macro_{lifecyclestageX\ ocean} = \sum(MPW_{lifecyclestageX} *\ LR_{countryY} * (RelR_{ocean} + RelR_{frw}) * RedR)$$

$$Leak\_macro_{lifecyclestageX\ otherterenv} = \sum(MPW_{lifecyclestageX} *\ LR_{countryY} * (RelR_{terenv}) * RedR)$$

This calculation can be done per product or polymer for a more detailed breakdown.

6.6 Sensitivity analysis

A sensitivity analysis should be performed to test parameters that either strongly influence the final leakage or are questionable. For instance, plastic product and packaging mass should be tested if they could not be estimated precisely. Loss rates calculated using municipal waste treatment data provided by the World Bank (Kaza et al. 2018) are a first proxy to estimate the plastic leakage rate. These country values can be tested if mismanaged waste rates do not seem appropriate to estimate a specific leakage pathway in a specific country identified as a hotspot.

6.7 Guidance for accessing more specific data sources

Specific data sources shall be used if (1) specific or regional waste treatment statistics are available to estimate the loss rate, (2) information on local informal waste collection practices are available to estimate the release rates, or (3) data on redistribution from one environmental compartment to another are available to estimate the redistribution rates.

Inventory of microplastic leakage from textiles

7

7.1 Introduction

This section addresses leakage of microplastics stemming from the abrasion of synthetic textiles during laundering. Namely, these leakages are synthetic microfibers from textiles, and are considered microplastics that can be aggregated with other leakages of micro- and macroplastics.

7.2 System map for the leakage of synthetic textile microfibers to the environment

This route covers synthetic microfiber losses during a product or corporate life cycle. In this section, microplastics represent synthetic microfibers of different polymers. Losses of macroplastics during textile production (e.g., lamination, sewing) or during product use (e.g., losses of microfibers during washing and wearing) and end-of-life should be assessed following the calculation route described in section 6 for plastic products and packaging.

Synthetic fibers, widely used in the textile and fishing industries, have been identified as one of the main sources of microplastic pollution in the marine environment (Carr 2017). Textile fibers are released into the environment, for instance, via household laundering in washing machines, which transfer wastewater to sewage systems and ultimately into freshwater or oceans, or applied to agricultural land (Cole and Sherrington 2016; Boucher and Friot 2017).

Numerous studies have identified synthetic microfibers as the preponderant weight among microplastics in samples collected around the world, including surface and subsurface sea water, beach sediments, estuarine sediments, coastal sediments and deep sea sediments (Salvador Cesa et al. 2017). Microplastics can also be transported in the atmosphere and deposited in remote, pristine mountain catchments such as the French Pyrenees (Allen et al. 2019a). These findings confirm the existence of clear pathways that enable primary microplastics to reach different environmental compartments.

Figure 7.1 presents the general methodological principles to account for plastic leakage to the environment applied to synthetic textile microfibers. Macroplastic losses occurring for example during lamination or sewing shall be accounted for by following the guidance on plastic products described in Section 6 “Inventory of macroplastic leakage from plastic waste”.

For each leakage pathway, three main calculation steps are foreseen:

- The loss (defined as the quantity of fiber that leaves a properly managed product or waste management system) is applied as a **loss rate** ($LR_{textile}$), which is the fraction of material that is detached from the plastic product during manufacturing, use or transport for microplastics or as mismanaged waste for macroplastics. Losses of different amounts of synthetic microfibers occur during each stage of the supply chain. It is understood that synthetic microfiber losses occur mainly through the wastewater pathway and the direct pathway (when no wastewater treatment infrastructure is available) at different life cycle stages: (1) pre-wash and processing during textile production, and (2) washing by hand or machine during the use stage. A washing machine filter may reduce the loss of synthetic microfibers during laundering by capturing some fibers before their transfer to a sewage system. These filters are then disposed of in the solid waste management system and assumed to be properly managed ultimately, i.e., disposed in landfill or incinerated. Synthetic microfibers can also be emitted into the air while the textile is being worn, dried in a clothes dryer, dry cleaned or recycled. These pathways are further described in section 7.3. Following these various **transfer pathways**, synthetic microfibers reach various environmental compartments. However, we do not provide guidance on how to quantify these emissions due to lack of relevant data.
- The release, translated into a **release rate** ($RelR$), is a measure of the plastic transported towards an initial environmental compartment such as freshwater, ocean or soil. This release depends considerably on the wastewater treatment and sewage sludge treatment infrastructure. The release rate is the fraction of the loss that is released.
- The redistribution, translated into a **redistribution rate** ($RedR$), is a measure of the plastic redistributed towards a final environmental compartment. The redistribution rate is the fraction of the release quantity that is redistributed in different environmental compartments.

For example, if a synthetic microfiber released during machine washing in a high-income country is not captured during wastewater treatment, it might reach waterways and ultimately be redistributed to oceans.

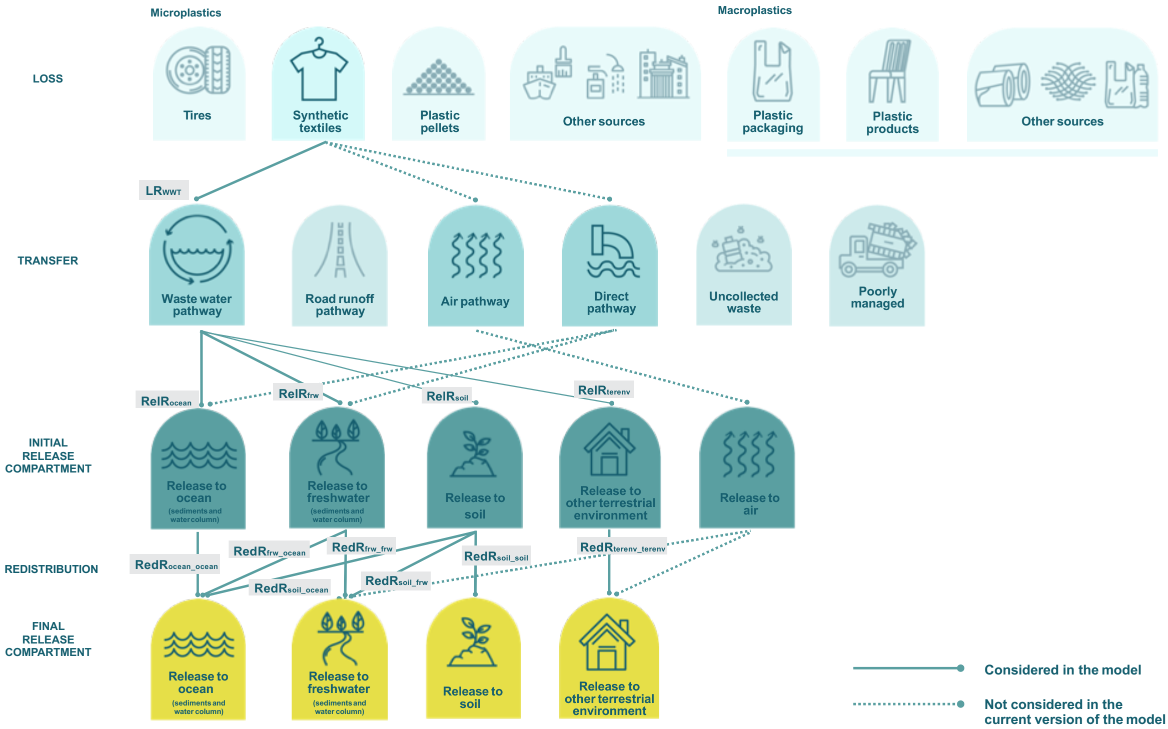


Figure 7.1: Losses, transfer pathways and plastic release compartments for synthetic microfibers from textiles

7.3 Loss rate: key parameters

Most studies on synthetic microfiber loss identify common key parameters that influence the loss during washing (measured in mg fibers/g fabric). These parameters relate to either garment characteristics or washing conditions and are summarized in the Figure 7.2.

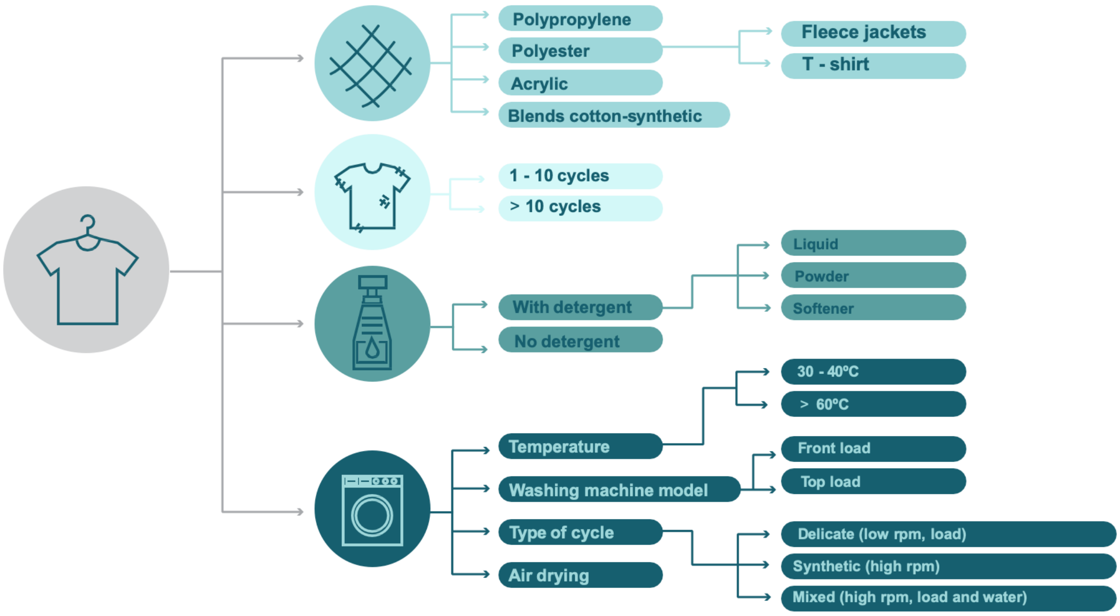


Figure 7.2 : Key parameters potentially influencing the loss rate of textile fibers

The main conclusions obtained so far on the influence of each key parameter are presented in Table 7-1. Numbers differ greatly from one study to another, so it is very difficult to give precise estimates of the mass of fibers released during a washing cycle. However, most studies show similar trends when it comes to the variations of the parameters.

Table 7-1: Degree of influence of key parameters

 **Type of fabric**	• Fleece appears to shed significantly more synthetic fibers than any other synthetic fabric (Browne et al. 2011; Folkö 2015; Åström 2016; Carney Almroth et al. 2018) . A possible explanation is the fact that the woven fibers are cut on the surface to give fleece its special features (Åström 2016). There is no difference between fleece and microfleece. Overall, fleece fabric releases more than 50% more fibers than other synthetic fabrics on average. However, in one study fleece released only around half the amount measured in other studies (Sillanpää and Sainio 2017). • Synthetic microfiber polymers with the highest loss rate are polyester, acrylic and polypropylene. The impact of blending synthetic and natural fibers remains unclear; in some cases, garments composed of 100% of these synthetic materials have a higher loss rate than a cotton-synthetics blend (Napper and Thompson 2016), while in other research the contrary is true (Zambrano et al. 2019). • How type of fabric (knitted or woven) and knitting techniques influence fiber release is still unclear. While some researchers find no statistical difference between different knitting techniques on the release of fibers from polyester (Hernandez et al. 2017; Belzagui et al. 2019), others conclude that woven polyester releases the most fibers compared to knit polyester (De Falco et al. 2018). Others again noted that more tightly knit fabrics shed more fibers, and that textiles using yarn with a greater number of exposed filaments per area shed more fibers than yarns with fewer (Carney Almroth et al. 2018).
 **Age of the fabric**	• Fiber shedding changes over time. New textiles release more fibers, and after about 5 washes the rate decreases significantly and can be considered as stabilized (Browne et al. 2011; Folkö 2015; Hartline et al. 2016; Pirc et al. 2016; Carney Almroth et al. 2018; Belzagui et al. 2019). Only one study found no significant decrease (Hernandez et al. 2017). • The number of fibers released seems to increase again as textiles age and become damaged. According to the studies that artificially aged textiles to reproduce used and torn clothes, the fiber shedding of old clothes is even higher than that of brand new ones (Åström 2016; Hartline et al. 2016; Carney Almroth et al. 2018).

Detergent use	• The use of detergent (liquid or powder) causes a higher release of synthetic fibers compared to when no detergent is added (Åström 2016; Napper and Thompson 2016; Hernandez et al. 2017; Carney Almroth et al. 2018; De Falco et al. 2018; Zambrano et al. 2019), while adding fabric softener may have a mitigating effect and reduce fiber loss by as much as 35% (De Falco et al. 2018). Mechanical stress should also be taken into account.
Washing machine settings	• Top load machines induce 5-7 times more shedding than front-load machines (Hartline et al. 2016; Napper and Thompson 2019). • Temperature is not considered a variable assuming that all washing is done at 30-40° C as typically recommended for synthetic fabrics, taking into consideration that nowadays higher temperatures are generally avoided thanks to a stronger "eco-awareness" and more effective detergents. • Tumble drying also drives up the rate of fiber loss, which can be up to 5 times higher than during washing (Pirc et al. 2016; Zambrano et al. 2019). • The duration of a cycle does not seem to influence the release rate (Hernandez et al. 2017).

Parameters influencing losses occurring during other life cycle stages, such as losses to the air during wearing and losses to wastewater during fiber production are still poorly understood and thus not covered in this guidance.

7.4 Initial release rate

Once synthetic microfibers are lost during the wash, their release is dependent on the wastewater treatment infrastructure. Wastewater treatment levels (primary, secondary and tertiary) vary significantly in how efficiently they remove synthetic microfibers. Storm water overflows during periods of heavy rain may cause direct release to waterways. Synthetic microfibers captured in sewage sludge may be applied to agricultural soils as fertilizers or disposed of through thermal treatment with energy recovery or deposited in engineered landfills, and are therefore prone to being transferred to waterways through runoff.

Figure 7.3 presents the different parameters influencing the release rates.

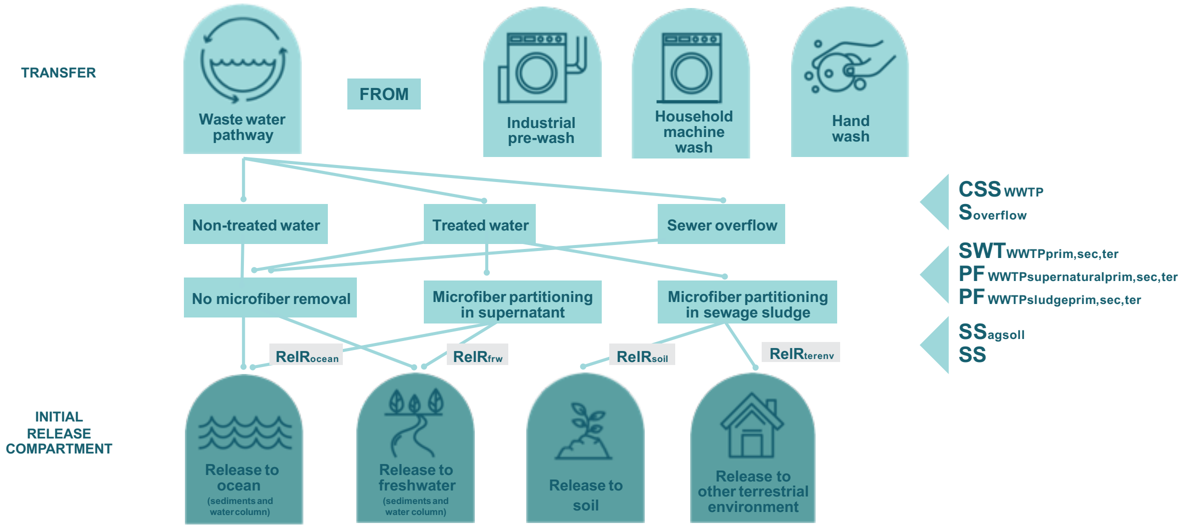


Figure 7.3: Zoom on the wastewater treatment pathway

Some authors have shown that at wastewater treatment, primary and secondary stages with skimming and sedimentation processes are very effective at removing synthetic microfiber fragments from the supernatant (or liquid fraction) (Carr et al. 2016). In particular, primary sedimentation with tertiary biological filtration decreases the proportion of synthetic microfibers in the supernatant while more synthetic microfibers are concentrated in the sludge fraction (Talvitie et al. 2015).

Microplastic or synthetic microfiber removal efficiencies at different treatment levels have been collected through a literature review (Magnusson and Norén 2014; Talvitie and Heinonen 2014; Dris et al. 2015; Talvitie et al. 2015; Carr et al. 2016; Murphy et al. 2016; Simon et al. 2018). Appendix B presents the 5th percentile, 1st quartile, median, 3rd quartile and 95th percentile values of the removal efficiency of different levels of treatment and the literature sources used for this analysis.

7.5 Redistribution rate

Synthetic microfibers released in freshwater may be trapped in freshwater sediments or follow waterways, in which case they are ultimately released to oceans. The ratio of synthetic fibers captured in freshwater sediments to the quantity of fibers released in freshwater is now estimated to be between 0.75 and 0.9% for laundry textiles made from polyamid, polystyrene and acrylic fabric (Siegfried et al. 2017).

Plastics deposited on agricultural soils through sewage sludge are assumed to be transported to oceans, freshwater or captured in agricultural soils.

7.6 Calculation routes for leakage

7.6.1 Data collection

The first step to start a plastic leakage analysis is to collect data on the mass of textile used $M_{textile}$, by types of polymer (if possible) including regionalized information on washing location. Data should be collected for all reference flows, according to the textile life cycle stages illustrated in Figure 7.4. This mass of textile used for a product or corporate footprint serves as a starting point to apply the loss/release/redistribution sequence as described in the next sections.

If information is available, textiles should be broken out by type of use, e.g., clothes, home textile (e.g., linen, towels, curtains), given that the use stage (especially the number of washes) can vary substantially depending on the use type.

Figure 7.4: Life cycle of a synthetic textile product

7.6.2 Calculation parameters

Table 7-2 presents the parameters used throughout the guidance in case no primary specific data are available. These generic values should be updated and refined as the state of the art evolves on this topic. These generic values should be applied during a product or corporate plastic leakage assessment when no measured data, or published primary data, are available that provide a more accurate representation.

All calculation parameters are summarized in the file *PLP_Sectorial_Guidances_Generic_data*.

Table 7-2: Parameters used to calculate the quantity of synthetic microfibers leaked to the environment

Abreviation	Description	Unit	Generic value if available	Reference
$M_{textile}$	Mass of textile used	kg textile used		
$MiPL$	Mass of synthetic microfiber loss	mg microfiber lost	Calculated	Loss rate for textiles during (1) pre-wash and processing during textile production and (2) washing by hand or machine during the use stage
LR	Loss per kg of textile washed over the textile life cycle	mg/kg textile wash	Calculated	
$LR_{perwash}$	Loss per kg of textile washed, per wash	mg/kg textile wash	46	Literature review presented in 6.5.3.
$RelR_{ocean}$ $RelR_{frw}$ $RelR_{soil}$ $RelR_{terenv}$	Release rate of synthetic microfibers through the sewage system respectively to freshwater, oceans, agricultural soils and terrestrial environment	%	Calculated	
$R_{f/m}$	Ratio of release between freshwater and oceans	%	74% in freshwater	Assumed to be proportional to population. Coastal population (<50 km from the coast) represents 26% of the world population (calculation based on Jambeck et al. (2015))
$RedR_{ocean\_ocean}$ $RedR_{frw_{ocean}}$ $RedR_{soil\_ocean}$ $RedR_{frw\_frw}$ $RedR_{soil_{frw}}$ $RedR_{soil\_soil}$ $RedR_{terenv\_terenv}$	Redistribution rate of synthetic microfibers from oceans, freshwater, soils and other terrestrial environment to oceans, freshwater sediments, agricultural soils and other terrestrial environments	%	Calculated	
N_{wash}	Number of washes for a textile garment during its lifetime	20	Estimation	Estimation to be refined for each specific product (e.g.,categories for different layer types for clothes)
CSS_{WWTP}	Connection to sewage system	%	Data per country	Country data compiled based on various sources (Van Drecht et al. 2009; Williams et al. 2012; Baum et al. 2013)
$SWT_{WWTPprim}$ $SWT_{WWTPsec}$ $SWT_{WWTPter}$	Share of type of treatment, for a given level of wastewater treatment e.g., primary, secondary or tertiary	%	Data per country	Country data compiled based on various sources (Van Drecht et al. 2009; Williams et al. 2012; Baum et al. 2013)
PF_{sludge}	Partitioning factor of synthetic microfibers to sludge in WWTP	%	96%	Literature review in Appendix B
$PF_{supernatant}$	Partitioning factor of synthetic microfibers to supernatant in WWTP	%	4%	Literature review in section Appendix B

$PF_{sludgeprim}$ $PF_{sludgesec}$ $PF_{sludgeter}$	Partitioning factor of synthetic microfibers to sludge in WWTP over the whole process for a given level of final treatment, e.g., primary, secondary or tertiary	%	81% 95% 98%	Literature review in Appendix B
$PF_{supernatantprim}$ $PF_{supernatantsec}$ $PF_{supernatantter}$	Partitioning factor of synthetic microfibers to supernatant in WWTP for a given level of final treatment, e.g., primary, secondary or tertiary	%	19% 5% 2%	Literature review in Appendix B
SS_{agsoil}	Share of sewage sludge deposited on agricultural soil	%	50%	Average value for Europe and North America from Carbonell et al. (2009); Bianchini et al. (2016); Nizzetto et al. (2016a). It is assumed that part of sewage sludge is mismanaged and the rest is incinerated or landfilled, and that no microplastics are released to air or soil (there is to date no data for microplastic loss rates after deposit in landfill)
$SS_{mismanaged}$	Share of sewage sludge that is mismanaged	%	11%	Bianchini et al. (2016). We consider the value of 10.7% which is the fraction of sludge for which the treatment of sludge remains "unknown" (EU 27).
$S_{Overflow}$	Share of overflow (due to wet weather conditions)	%	5%	Expert estimation
$R_{freshsed}$	Ratio of synthetic microfibers captured in freshwater sediments	%	30%	Hurley et al. (2018) demonstrated that flooding exported approximately 70% of the microplastic load stored on river beds. We thus estimate that only 30% of microfibers are ultimately stored in freshwater sediments. This preliminary estimate may be refined by performing a wider literature review.
R_{soil}	Ratio of synthetic microfibers captured in soil	%	27%	From 16% to 38% Nizzetto et al. (2016a), i.e. 27% on average
$Leak\_micro$	Leakage of synthetic microfibers	mg	Calculated	

7.6.3 Calculation rules for loss rates

Production

Given the lack of quantified data on losses during textile production stages, we suggest using the same loss rate as that of the use stage, assuming overall the equivalent of 5 washes.

Use stage

The equations to calculate the loss rate LR_{WWP} for synthetic textile microfibers lost during the use stage are presented in Figure 7.5 and below. We consider that synthetic microfibers are lost and transferred either to wastewater, air or directly to freshwater or oceans.

Limitations

This guidance only covers leakage from microfibers lost and transferred to wastewater due to the lack of data on other types of losses.

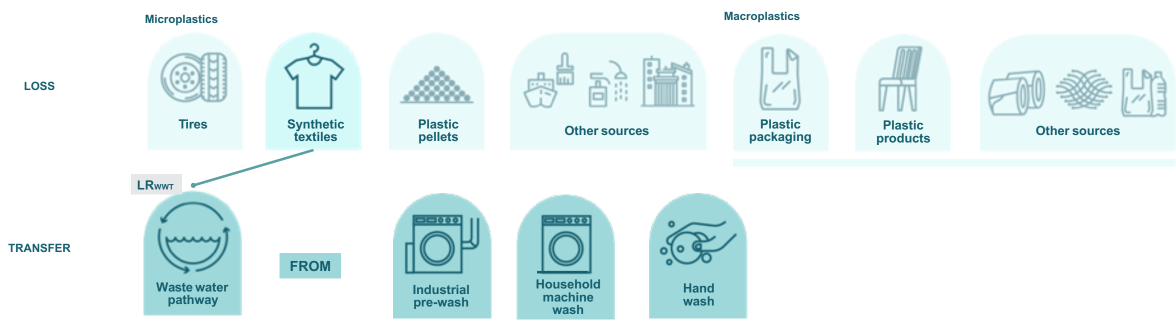


Figure 7.5: Loss rates for synthetic microfibers

LR_{WWP} represents the loss rate for textiles during (1) pre-wash and processing during textile production, and (2) washing by hand or machine during the use stage, in case sewage water is connected to a wastewater treatment plant.

There is growing interest in how much microfiber is shed from fabrics during washing, and many studies are conducted on this topic. A plethora of loss rate values are reported in the literature. This is probably due to both the lack of a standardized methodology that measures release during laundering, and also extremely variable loss rates for the key parameters described above. Appendix C shows the 5th percentile, 1st quartile, median, 3rd quartile and 95th percentile values for the loss rates per textile group as well as literature sources used for this analysis. These results show that there is no clear influence of pre-defined parameters.

As a consequence, the central, low and high values for the loss rates are based on all values reported in the literature, with loss rates of low/central/ high value of **24/46/134 mg/kg textile wash respectively.**

The following equation can be used to calculate the mass of synthetic microfiber loss $LR_{textile}$ over a textile life cycle (in g microfiber / kg textile wash).

$$LR_{WWP} = N_{wash} * LR_{perwash}$$

The following equation can be used to calculate the mass of synthetic microfiber loss $MiPL$ over a textile life cycle (in g microfiber).

$$MiPL = N_{wash} * LR_{perwash} * M_{textile}$$

End-of-life

The plastic lost during the end-of-life stage can be considered as macroplastic loss, and thus should be accounted for according to the plastic products and sectorial guidance. Secondary microplastics from plastic products and packaging weathering are not included in this guidance due to lack of data.

7.6.4 Calculation rules for release rates

The equations to calculate global release rates $RelR_{ocean}$, $RelR_{frw}$, $RelR_{soil}$ and $RelR_{terenv}$, for synthetic microfibers are presented in Figure 7.6 and below.

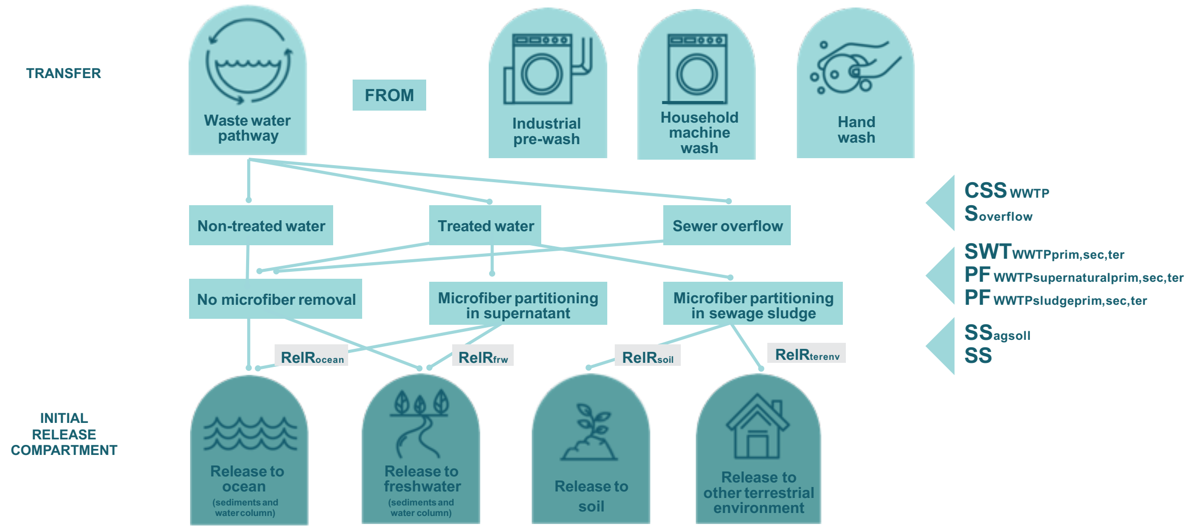


Figure 7.6: Release rates leading from the wastewater treatment pathway to the initial release compartment for synthetic microfibers

$RelR_{ocean}$ and $RelR_{frw}$ represent the release of synthetic microfibers through the sewage system to freshwater and oceans. This release can be calculated based on the connection to sewage system CSS_{WWTP}, the share of overflow $S_{Overflow}$, the share of wastewater treatment plants equipped with a primary treatment $SWT_{primary}$, secondary treatment $SWT_{secondary}$ and tertiary treatment $SWT_{tertiary}$ as well as a partitioning factor of synthetic microfibers to supernatant for each treatment level $PF_{WWTPsupernatantprim}$, $PF_{WWTPsupernatantsec}$ and $PF_{WWTPsupernatantter}$.

The ratio of release between freshwater and oceans is expressed as $R_{f/m}$.

$RelR_{soil}$ represents the release rate of synthetic microfibers through wastewater treatment sludge to agricultural soils and $RelR_{terenv}$ to other terrestrial environments. We then use the share of sewage sludge deposited on agricultural soil SS_{agsoil} as well as the share of sewage sludge that is mismanaged $SS_{mismanaged}$ to estimate the share of captured synthetic microfibers that are applied to agricultural soils and other terrestrial environments (we assume that the rest is disposed of or incinerated).

$$RelR_{ocean} + RelR_{frw} = 1 - CSS_{WWTP} * (1 - S_{Overflow} - SWT_{WWTPprim} * PF_{WWTPsupernatantprim} - SWT_{WWTPsec} * PF_{WWTPsupernatantsec} - SWT_{WWTPter} * PF_{WWTPsupernatantter})$$

$$RelR_{frw} = R_{f/m} * (RelR_{ocean} + RelR_{frw})$$

$$RelR_{ocean} = (1 - R_{f/m}) * (RelR_{ocean} + RelR_{frw})$$

$$RelR_{soil} = \left(1 - \left(RelR_{ocean} + RelR_{frw}\right)\right) * SS_{agsoil}$$

$$RelR_{terenv} = \left(1 - \left(RelR_{ocean} + RelR_{frw}\right)\right) * SS_{mismanaged}$$

7.6.5 Calculation rules for redistribution rates

The equation to calculate redistribution rates $RedR$ for packaging and non-packaging waste is presented in Figure 7.7 and below.

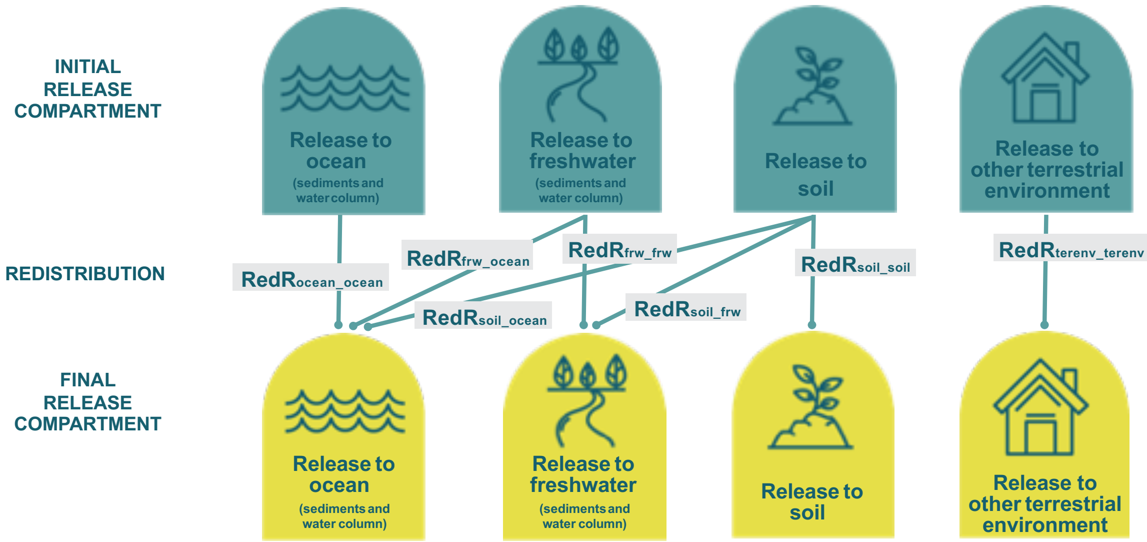


Figure 7.7: Redistribution rates for synthetic microfibers

Redistribution of synthetic microfibers released initially to ocean

It is assumed that all synthetic microfibers released to oceans remain in oceans.

$$RedR_{ocean\_ocean} = 100\%$$

Redistribution of synthetic microfibers released initially to freshwater

It is assumed that synthetic microfibers released to freshwater are partly released into oceans and partly trapped in freshwater sediments. Various studies estimate the fraction of synthetic microfibers trapped in freshwater sediments. We use the ratio of synthetic microfibers captured in freshwater sediments $R_{freshsed}$ to calculate $RedR_{frw\_ocean}$ and $RedR_{frw\_frw}$.

$$RedR_{frw\_ocean} = 1 - R_{freshsed}$$

$$RedR_{frw\_frw} = R_{freshsed}$$

Redistribution of synthetic microfibers released initially to soils

It is assumed that synthetic microfibers released to soils are either retained in soil or transferred to oceans or freshwater where they can be trapped in freshwater sediments. We use the ratio of synthetic microfibers captured in soil R_{soil} as well as $R_{freshsed}$ to calculate $RedR_{soil\_ocean}$, $RedR_{soil\_frw}$ and $RedR_{soil\_soil}$.

$$RedR_{soil\_soil} = R_{soil}$$

$$RedR_{soil\_ocean} = (1 - R_{soil}) * (1 - R_{freshsed})$$

$$RedR_{soil\_frw} = (1 - R_{soil}) * R_{freshsed}$$

Redistribution of synthetic microfibers released initially to other terrestrial environments

It is assumed that synthetic microfibers released to other terrestrial environments remain in other terrestrial environments.

$$RedR_{terenv\_terenv} = 100\%$$

7.6.6 Leakage

The leakage of synthetic microfibers $Leak\_micro$ in different environmental compartments is ultimately calculated as the sum of synthetic microfiber waste lost ($MiPL$) during a product life cycle or a corporate activity, multiplied by the release ($RelR$) and the redistribution rates ($RedR$) to different environmental compartments:

$$Leak\_micro_{oceans} = \sum(MiPL * (RelR_{ocean} * RedR_{ocean\_ocean} + RelR_{frw} * RedR_{frw\_ocean} + RelR_{soil} * RedR_{soil\_ocean})$$

$$Leak\_micro_{freshwater} = \sum(MiPL * (RelR_{frw} * RedR_{frw\_frw} + RelR_{soil} * RedR_{soil\_frw})$$

$$Leak\_micro_{soil} = \sum(MiPL * RelR_{soil} * RedR_{soil\_soil})$$

$$Leak\_micro_{terenv} = \sum(MiPL * RelR_{terenv} * RedR_{terenv\_terenv})$$

7.7 Sensitivity analysis

A sensitivity analysis should be performed to test parameters that have a high uncertainty or high influence on the final leakage. For instance, the number of washes should be tested if it could not be estimated. The loss rates are calculated based on literature review averages, and therefore low and high loss rates can be tested, respectively **24** and **134 mg/kg** textile washed.

7.8 Guidance for accessing more specific data sources

In case more specific data sources are available for loss rates during a textile life cycle,

Table 7-3 presents an example of synthetic microfiber emissions and measurement techniques that may be used to evaluate them.

Table 7-4 present a data collection template to collect data according to each measurement method:

a. Mass balance at site level
b. Air filter monitoring (weight + number of replacement)
c. Dust collection inventory
d. Wastewater synthetic microfiber concentration measurement

Table 7-3: Loss rate specific data collection for each textile product life cycle stage

		Raw material extraction and processing	Spinning of yarn from filament and stable fibers	Knitting and weaving of yarn into fabric	Bleaching and dyeing of fabric as well as fabric finishing	Cutting and sewing fabric into apparel products
Example of processes			Pre-oriented yarns, rotor spinning, winding		Dyeing, width opening, stenter, raising, combing, shearing	Lamination, Durable Water Repellent (DWR) coating
LEAKAGE IN THE FORM OF MICRO-FIBRES	What?		Emissions into air Indoor dust	Emissions into air and water	Emissions into water	
	How to measure?		a. Mass balance at site level b. Air filter monitoring (weight + number of replacement) c. Dust collection inventory	a. Mass balance at site level b. Air filter monitoring (weight + number of replacement) c. Dust collection inventory d. Wastewater micro-plastic concentration measurement	d. Wastewater micro-plastic concentration measurement	
	Please assess the importance of the loss	✓ High ✓ Average ✓ Low	✓ High ✓ Average ✓ Low	✓ High ✓ Average ✓ Low	✓ High ✓ Average ✓ Low	✓ High ✓ Average ✓ Low

Table 7-4: Data collection template for each data collection method

Data to collect	Value (t /y)	Reference
a. Mass balance at site level		
Total plastic input in the site		E.g.,financial accounting, purchasing invoice
Total output in the form of manufactured product		E.g.,financial accounting, purchasing invoice
Plastic waste generated		E.g.,cost of waste management, weight accounting
b. Air filter monitoring		
Air filer replacement rate		E.g.,maintenance team, data from sub-contractors, purchasing records
Weight of plastic dust in the filter		Needs to be measured
Site production capacity		E.g.,annual statistics
c. Dust collection inventory		
Quantity of dust collected on the floor on a daily basis		E.g.,maintenance team, data from sub-contractors, purchasing records
Production capacity		Needs to be measured
d. Wastewater synthetic microfiber concentration		
Quantity of fibers in wastewater		E.g.,maintenance team, data from sub-contractors
Quantity of fibers in wastewater sludge		E.g.,maintenance team, data from sub-contractors
Production capacity		Needs to be measured

Inventory of microplastic leakage from tire abrasion during transport

8

8.1 Introduction

This section addresses the leakages of microplastics related to tire abrasion[9] on road/strip surfaces for road transport and air transport[10]. Specifically, these leakages refer to the polymer fraction of tire tread and are referred to as “microplastic leakages from tire tread losses” in the following section. In the present document the polymer fraction is considered a microplastic and therefore can be aggregated with the other micro- and macroplastic leakages.

These sectoral guidelines may be considered in the context of passenger transport (e.g., business travels, commuting) and goods transport (e.g.,distribution transport) and can be applied to the following types of vehicles:

- Passenger car and light truck
- Medium/heavy truck
- Bus/coach
- Motorcycle
- Aircraft

The current sectoral guidelines consist of two different sections for the calculation of tire wear loss depending on the focus of the study:

- For non-tire related studies, calculation rules are shown in section 8.7.3. This section indicates default values that are not specific to a type of tire but that represent an average per type of vehicle;
- For tire-related studies, calculation rules are shown in section 8.7.4. This section presents equations that can be used to calculate the loss rate related to a specific tire depending on its characteristics[11].

[9] Leakages of microplastics from road markings and brake abrasion are not included in this study due to the lack of quality data; furthermore, these sources contribute relatively little compared to tire abrasion. A literature review on the subject is presented in Appendix E.

[10] Leakages of microplastics from boat coatings are not included in this study due to the lack of data. In addition there is a consensus among experts that such leakages are very low compared to other transport microplastic emissions.

[11] For tire-related studies, leakages related to tire end-of-life should be calculated according to section 8.7.4.

8.2 Tire and road wear particles and tire tread losses: preliminary explanation

Particles resulting from the abrasion of tire tread on road surfaces are one of the main sources of microplastic losses in the environment (Kole et al. 2017). Tire tread particles are a matrix of synthetic polymers, namely Styrene Butadiene Rubber, natural rubber and other additives (MEPEX, 2014). The tire wear particles are always embedded with pavement particles (Kreider et al. 2010); together they form tire and road wear particles (TRWP), which are then emitted to the environment. The exact proportions vary depending on many factors. An average ratio of 50% tread wear and 50% road wear can be used (Unice et al. 2019b). Behavior of particles in the environment depends on the physical properties of TRWP and not the physical properties of tire tread alone, and these can differ considerably. For example, the transfer and redistribution of particles are dependent on their density (among other factors), which is around 1.8 g/cm^3 for TRWP while only 1.2-1.4 g/cm^3 for tire tread. The release rate and redistribution rate are presented in Sections 8.5 and 8.6.

However, to perform a plastic leakage assessment, it is then necessary to exclude from the inventory the road fraction of TRWP, since this fraction is mainly mineral material. In addition, in this fraction of tire tread from the TRWP, it is then necessary to account for only the polymer fraction, i.e., the natural rubber and the synthetic rubber, this proportion in tire tread is detailed inTable 8-6. **For coherence with the rest of the guidelines, the leakages of this polymer fraction to the environment is called "microplastics from tire abrasion".**

The approach is summarized in Figure 8.1.

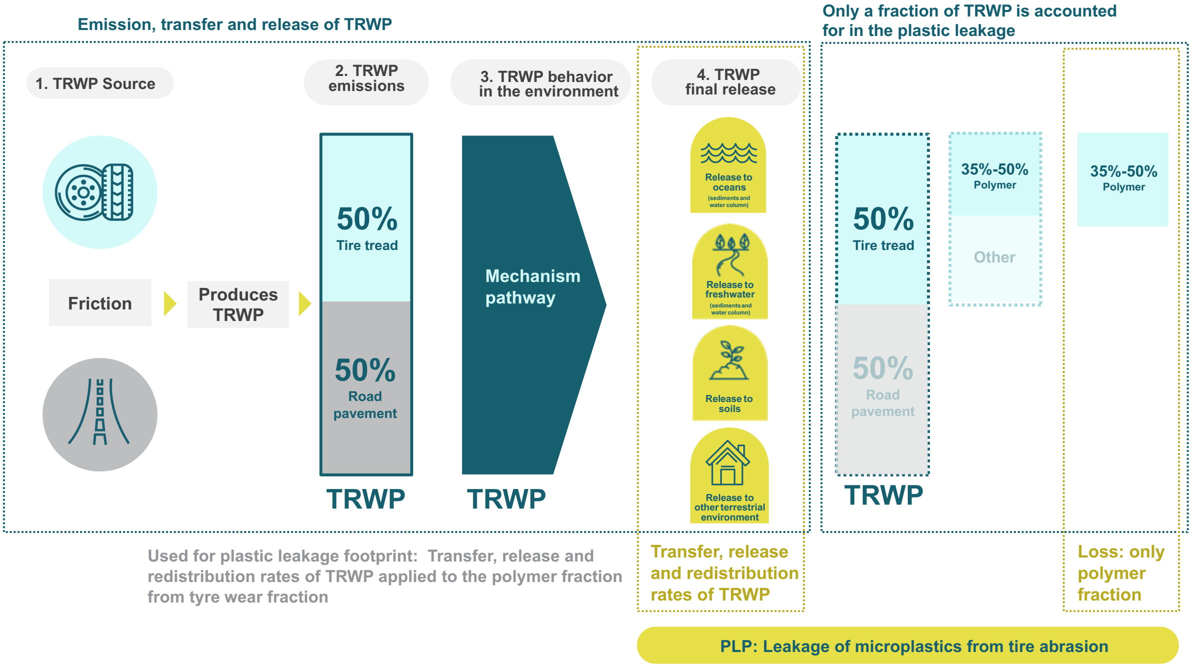


Figure 8.1: Tire and Road Wear Particles (TRWP) and calculation of leakage of microplastics from tire abrasion; the behavior of TRWP (i.e. the transfer, release and redistribution) is considered, but applied only to the theoretical fraction of polymer from tire fraction of TRWP

8.3 System map for the leakage of microplastics from tire abrasion to the environment

As explained in section 8.2, tire tread particles are always incrusted with pavement particles and form together the TRWP, but only the polymer fraction from the tire fraction of TRWP is taken into account to quantify tire tread losses ($\mathrm{TireLoss}_{\mathrm{vehicle}}$). The tire tread losses are further described in section 8.4 and the calculation rules are presented in sections 8.7.3 and 8.7.4.

There are different **transfer pathways,** which are further described in section 8.5:

- a small fraction (from 1% to 7% depending on the study (Unice et al. 2018) of TRWP are particles below 10 μm which are emitted to air
- the main portion of TRWP above 10 μm is deposited to soil near the road (from 49% to 85% depending on the study (Unice et al. (2018) and Hann et al. (2018))
- the remaining portion of TRWP above 10 μm is deposited on the road, from which a fraction gets trapped in the asphalt, the other fraction transported by rainwater runoff

Following these various transfer pathways, microplastics from tire tread losses are **released** in various **initial environmental compartments** such as air, freshwater, oceans or soils. The **release rate** ($\mathrm{RelR}_{\mathrm{compartment}}$) is defined as the fraction of the loss that is released in the different compartments listed below, and is described further in section 8.5.

As explained above:

- the TRWP below 10 μm are emitted into **air**
- the TRWP above 10 μm deposited near the road are emitted into **soil**
- the TRWP above 10 μm transported by runoff water are released into soils, surface **water or oceans or sewer systems** depending on the type of road and the country. From sewer systems, release in the different environmental compartment depends on the type of sewer system (combined system, which brings the runoff water to waste water treatment plant, or separated system, which brings the runoff water directly to surface water), the efficiency of wastewater treatment and sewage sludge treatment infrastructure.

Finally, TRWP released in the different initial compartments can be **redistributed** towards other **final environmental compartments**. For example, if released TRWP are not captured by a combined sewer system nor at the later stage of wastewater treatment, they might reach freshwater sediments or stay in suspension in waterways and ultimately be redistributed to oceans. The **redistribution** rate ($RedR$) is the fraction of the release that is redistributed in different environmental compartments and is further described in section 8.6.

Figure 8.2 represents the main methodological principles to account for plastic leakage to environment applied to microplastics leakages from tire abrasion. The detailed pathway from road runoff water through the different types of infrastructures (combined sewer, separated sewer, etc) is further described in section 8.5.

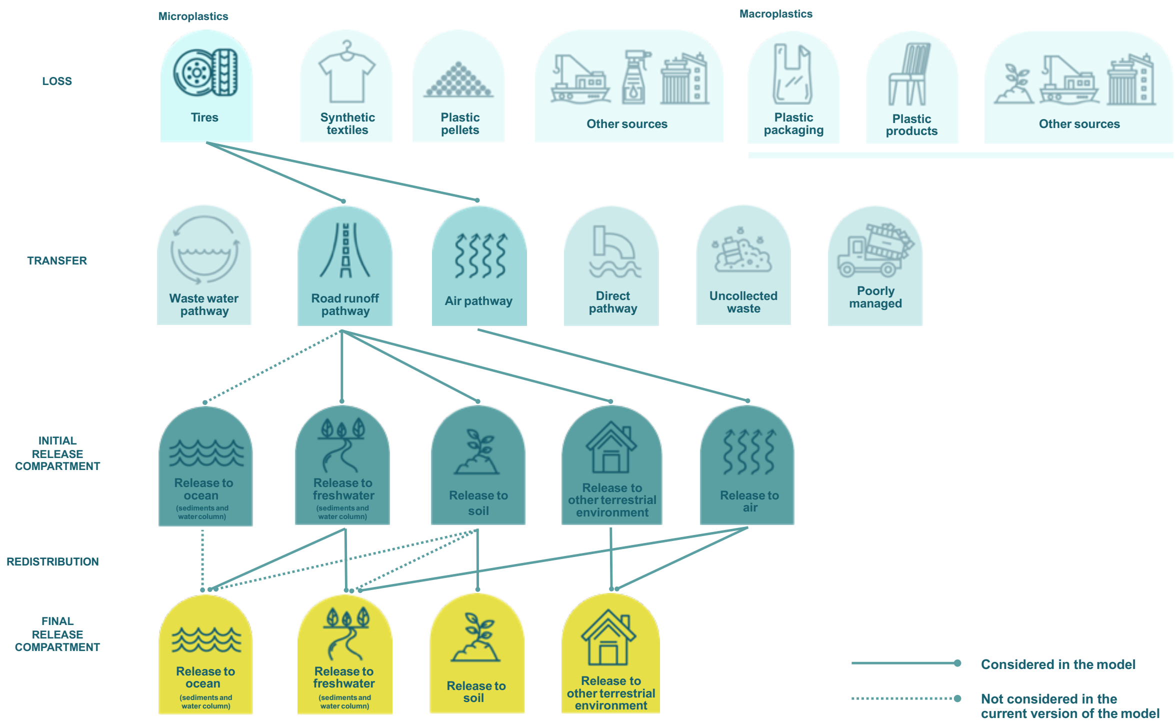


Figure 8.2: Summary of losses, transfers, pathways and plastic release compartments for microplastics from tire abrasion

8.4 Loss rate: key parameters

There are many different factors that affect tire tread abrasion rate (defined as the total amount of matter lost from tire tread due to interaction with the road per unit of distance and expressed as mg TRWP / km driven). Some studies identify common key parameters that influence the loss of tire tread. These parameters include:

- Intrinsic tire design characteristics, such as tread rubber formulation and distribution of the forces in the tire-road contact area
- Vehicle characteristics (weight, load distribution, location of driving wheels, suspension)
- Road surface characteristics (material, roughness, humidity, pollutants, weather conditions) and road topology (hilly/winding vs flat/straight)
- Driving behavior characteristics (sporty vs smooth driving, high vs moderate speed, inflation pressure, braking, cornering).

External factors such as driving behavior, road conditions and vehicle characteristics can cumulatively have a larger influence on tire tread abrasion rates than the tire design alone. However, the influence of these parameters has not clearly been elucidated yet, with the exception of vehicle type, for which a clear influence is observed (Boucher and Friot 2017).

For non-tire-related studies, the parameters that may be considered are:

- Type of vehicle (mainly the influence of the vehicle weight)
- Type of road - urban, rural or motorway (influence of the driving cycle)

Different loss rates are available for different types of vehicles and different types of road. The calculation guidelines for loss rates for tire abrasion are presented in section 8.7.3 for non-tire-related studies. For tire-related studies, the loss rate is calculated according to parameters of tire design, such as tread volume and density, contact width, void ratio and outer radius. The calculation guidelines for loss rates for tire abrasion are presented in section 8.7.4 for tire-related studies.

8.5 Initial release rate

Once TRWP are emitted during driving or aircraft landing, the release depends on i) meteorological conditions, since it influences rainwater runoff, and ii) the type of system for collecting water runoff; rainwater can flow directly into surface waters or a sewer system, either a combined system that directs all inflow to a wastewater treatment plant or a separated system that directs rainwater into surface water or a rainwater treatment system. However, in the absence of hard data, it is assumed that rainwater going through a separated system is discharged directly into surface water (Unice et al. 2018). The type of road (rural, urban or highway) has a significant influence on the type of sewer system and the treatment of runoff water.

In addition, location of the road has a significant influence on the type of surface water in which runoff water is discharged when leaving the sewer system; in coastal areas, runoff water may be released directly in the oceans, while in other areas runoff water is released in freshwater systems.

Important Note: At the time this document was released, there was no data available on the proportion of roads releasing runoff into freshwater versus oceans. The current version of the guidelines utilized therefore a single case of release into freshwater. This is one of the key limitations of the guidelines, which is further described in section 8.7.5.

The type of wastewater treatment also influences the rate, since it can have different efficiencies of microplastic removal. In addition, the treatment of sludge from wastewater treatment plants influences the release rate; a fraction of the sludge is spread on fields (release into soils), while a fraction of the sludge is incinerated or deposited in engineered landfills [12].

Storm water overflows during periods of heavy rain may cause direct release to waterways.

12 The fraction of sludge that is mismanaged (neither spread, neither landfilled or incinerated) is released in “other terrestrial environment”.

8.6 Redistribution rate

TRWP released in freshwater are either trapped in freshwater sediment or carried by waterways and ultimately released to oceans.

The sedimentation of TRWP depends on multiple parameters; some are related to the particle itself, such as its density, size and shape, while others are specific to the hydrology of the lake or river system, including size of the watershed, meteorological conditions, and the geographical area (coastal or continental areas).

Important Note: At the time this document was released, there were no robust data for evaluating the sedimentation rate in coastal areas (which represents a smaller distance from the point of release to the sea) or the retention rate in runoff water infrastructures. The same sedimentation rate of 90%[13] (Unice et al. (2018)) was therefore assumed for small and large watersheds., i.e., 90% of TRWP released in freshwater are deposited into freshwater sediments. This is one of the key limitations of the guidelines, which is further described in section 8.7.6.

TRWP deposited on agricultural soils through sewage sludge is assumed to remain in soils.

TRWP released into air are assumed to be deposited in other final compartments, such as soil or freshwater, due to sedimentation and/or washing out by rainwater.

Figure 8.3 presents the different parameters influencing the redistribution rates.

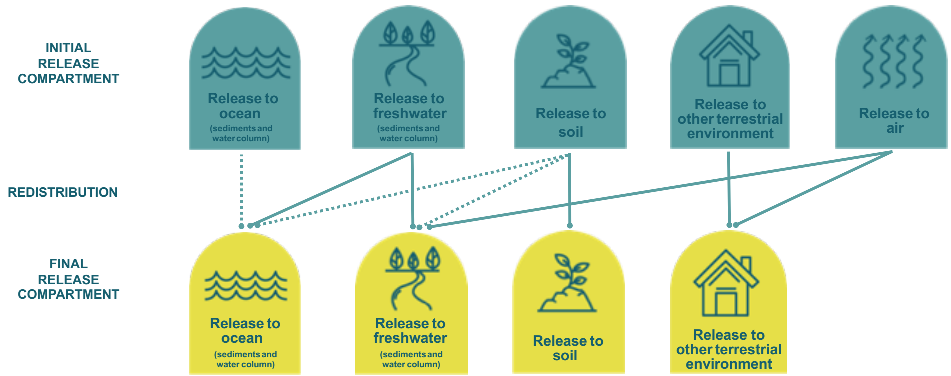


Figure 8.3: Redistribution rates and final release compartments

13 It should be noted that the value of 90% calculated in Unice et al. (2018) refers to the part of TRWP reaching estuaries. However, since no better data are available, it is a preliminary assumption that reaching the estuaries is tantamount to reaching the ocean.

8.7 Calculation routes for leakage

8.7.1 Data collection

The first step to commence an analysis of microplastic leakage from tire abrasion is to collect relevant data.

All life cycle stages of a product or a company that include transport shall be assessed, including transport of goods (e.g., for distribution or transport from suppliers), and transport of passengers (e.g., business travel and commuting).

The data to be collected are:

- Number of passengers and related distances travelled per type of vehicle for road transport of passengers
- Mass of product and related distance travelled per type of vehicle for road transport of goods
- Number of passengers and related number of flights (i.e., number “take-off, landing and taxiing” cycles) for transport of passengers by plane

8.7.2 Calculation parameters

The parameters for calculating the TRWP loss rates are provided in sections 8.7.3 and 8.7.4. Table 8-1 presents the default parameters used to calculate initial release rates, redistribution rates and final release rates. These generic values shall be updated and refined as the state of the art evolves on this topic. These generic values shall be applied for calculating microplastic leakage from tire abrasion during the transport stages of either a product life cycle or a corporate footprint.

All calculation parameters are summarized in the file *PLP_Sectorial_Guidances_Generic_data*.

Table 8-1: Parameters used to calculate the initial release rates, redistribution rates and final release rates of TRWP leaked to the environment

Abreviation	Description	Unit	Generic value if available	Reference
TotTireLoss	Losses of microplastics related to tire abrasion on road surfaces for the transport of passengers or goods by car/motorcycle/coach/truck/plane	kg (microplastics)	n/a (Calculated)	
$RelR_{ocean}$ $RelR_{frw}$ $RelR_{soil}$ $RelR_{terenv}$ $RelR_{air}$	Initial release rate TRWP through runoff water and air respectively to oceans, freshwater, soils, terrestrial environment and air.	%	n/a (Calculated)	n/a
Sh_{rural} Sh_{urban} $Sh_{highway}$	Share of rural roads, urban roads and highways	%	40% 33% 27%	Unice et al. (2018) Can be adapted depending on the country
$MajDistr_{rural\_air}$ $MajDistr_{rural\_soil}$ $MajDistr_{rural\_runoff}$	First major distribution for rural roads	%	2% 83% 15%	Hann et al. (2018), validated by Jos van Gils, July (2019)
$MajDistr_{urban\_air}$ $MajDistr_{urban\_soil}$ $MajDistr_{urban\_runoff}$	*First major distribution for urban roads*	%	2% 29% 69%	Hann et al. (2018), validated by Jos van Gils, July (2019)
$MajDistr_{highway\_air}$ $MajDistr_{highway\_soil}$ $MajDistr_{highway\_runoff}$	*First major distribution for highways*	%	2% 39% 59%	Hann et al. (2018), validated by Jos van Gils, July (2019)
$ShSepSewer_{rural}$ $ShSepSewer_{urban}$ $ShSepSewer_{highway}$	Share of runoff water going through separated sewage system or directly to freshwater (no system) for rural roads, urban roads and highways	%	25% 25% 50%	Unice et al. (2018) Can be adapted depending on the country
$ShCombSewer_{rural}$ $ShCombSewer_{urban}$ $ShCombSewer_{highway}$	Share of runoff water going through combined sewage system for rural roads, urban roads and highways	%	0% 75% 0%	Unice et al. (2018) Can be adapted depending on the country
$ShDitches_{rural}$ $ShDitches_{urban}$ $ShDitches_{highway}$	Share of runoff water draining into ditches	%	75% 0% 0%	Unice et al. (2018) Can be adapted depending on the country
$ShStormMgt_{rural}$ $ShStormMgt_{urban}$ $ShtormMgt_{highway}$	Share of runoff water going through storm water management systems	%	0% 0% 50%	Unice et al. (2018) Can be adapted depending on the country

Eff_{WWTP}	WWTP removal efficiency	%	95%	Unice et al. (2018) Can be adapted depending on the country (cf values in global guidelines and sectoral textile guidelines)
SS_{agsoil}	Share of sewage sludge deposited on agricultural soil	%	50%	Average value for Europe and North America from Carbonell et al. (2009), Bianchini et al. (2016), Nizzetto et al. (2016b) It is considered that a part is mismanaged and the rest of the sewage sludge is incinerated or landfilled and that no microplastics are released to air or soil (there is to-date no data for microplastic loss rates after deposition in landfill)
$SS_{mismanaged}$	Share of sewage sludge that is mismanaged	%	11%	(Bianchini et al. (2016). We assume the value of 10.7%, which is the fraction of sludge for which treatment remains "unknown" (EU 27).
$S_{Overflow}$	Share of overflow (due to wet weather conditions) (CSO)	%	5%	Unice et al. (2018)
$R_{freshsed}$	Ratio of TRWP captured in freshwater sediments	%	90%	Unice et al.(2018) Can be adapted depending on the country
R_{soil}	Ratio of TRWP captured in soil	%	100%	Unice et al. (2018) Can be adapted depending on the country
$RedR_{ocean\_ocean}$ $RedR_{frw_{ocean}}$ $RedR_{frw\_frw}$ $RedR_{soil\_soil}$ $RedR_{terenv\_terenv}$ $RedR_{air\_frw}$ $RedR_{air\_terenv}$	Redistribution rate of TRWP from oceans, freshwater, soil, other terrestrial environments and air to oceans, freshwater sediments, agricultural soils and other terrestrial environments	%	Calculated	n/a
$Leak\_micro$	Leakage of TRWP	mg	Calculated	

8.7.3 Calculation rules for tread losses for non-tire-related studies

Passenger transport by car

The equation for calculating tire abrasion losses of passenger transport by car is the following, if available data include the distance travelled by one or more vehicle(s):

$$\mathrm{TotTireLoss_{car}}\,[kg\ microplastics] = \mathrm{D_{car\_vhc}}[vhc * km] * \mathrm{Loss_{car\_tires}}\left[\frac{kg\ tread}{vhc * km}\right] * \mathrm{ShPolymer_{car\_tires}}[\frac{kg\ microplastics}{kg\ tread}]$$

OR:

If available data include the distance travelled by car by one or more passengers, the following equation shall be used:

$$\mathrm{TotTireLoss_{car}}[kg\ microplastics] = \frac{\mathrm{D_{car_{pass}}}[km] * \mathrm{Nb_{pass}}\,[pers]}{\mathrm{Pass_{av}}[pers/vhc]} * \mathrm{Loss_{car_{tires}}}\left[\frac{kg\ tread}{vhc * km}\right] * \mathrm{ShPolymer_{car_{tires}}}[\frac{kg\ microplastics}{kg\ tread}]$$

For this calculation, the following parameters are needed:

Table 8-2: Parameters for calculating the tire abrasion losses for transport of passenger by car

AbBreviation	Description	Unit	Generic value if available	Reference
$TotTireLoss_{car}$	Losses of microplastics related to tire abrasion on road surfaces for the transport of passenger by car	kg (microplastics)	n/a (to be calculated)	**N/A**
D_{car_vhc}	Distance travelled by car by the entire vehicle (vhc)	vhc*km	n/a (primary data to be provided)	n/a
D_{car_pass}	Distance travelled by car by passenger(s)	km	n/a (primary data to be provided)	n/a
Nb_{pass}	Number of passengers travelling over D_{car_vhc}	pers	n/a (primary data to be provided)	n/a
$Pass_{av}$	Average number of passengers per vehicle	Pers/vhc	If no primary data are available, see Table 8-7	See Table 8-7
$Loss_{car\_tires}$	Loss of tire tread per kilometer travelled by the vehicle	kg (tread)/ (vhc*km)	See Table 8-5	Literature review (see Appendix D)
$ShPolymer_{car\_tires}$	Share of polymer (synthetic rubber + natural rubber) in tire tread	kg (microplastics)/ kg (tread)	See Table 8-6	ETRMA (data provided 29.05.2019)

Passenger transport by motorcycle

The equations for calculating the tire tread losses of passenger transport by motorcycle are the same as those for transport by passenger car, using the parameters for motorcycles (see Table 8-5, Table 8-6 and Table 8-7).

Passenger transport by bus or coach

The equation for calculating tire tread losses of passenger transport by bus or coach are the same as those for transport by car, using the parameters for bus or coach (see Table 8-5, Table 8-6 and Table 8-7).

Goods transport by truck (light, medium and heavy trucks)

The equation for calculating tire tread losses of goods transport by truck is the following if the data available include distance travelled by one or more vehicle(s):

$$\begin{aligned}\mathrm{TotTireLoss}_{\mathrm{truck}}[kg\ microplastics] \\ = \mathrm{D}_{\mathrm{truck\_vhc}}[vhc * km] * \mathrm{Loss}_{\mathrm{truck\_tires}}\left[\frac{kg\ tread}{vhc * km}\right] \\ * \mathrm{ShPolymer}_{\mathrm{truck\_tires}}\left[\frac{kg\ microplastics}{kg\ tread}\right]\end{aligned}$$

OR:

If the data available is the mass of products transported over a certain distance, the ratio of the mass of products ($\mathrm{M_{prod}}$) compared to total load ($\mathrm{Load_{av}}$) of the truck shall be added to the calculation, and the following equation shall be used:

$$\begin{aligned}\mathrm{TireLoss}_{\mathrm{truck\_prod}}[kg\ microplastics] \\ = \frac{\mathrm{D}_{\mathrm{truck\_prod}}[km] * \mathrm{M}_{\mathrm{prod}}\ [kg]}{\mathrm{Load}_{\mathrm{av}}\ [kg]} * \mathrm{Loss}_{\mathrm{truck\_tires}}\left[\frac{kg\ tread}{vhc * km}\right] \\ * \mathrm{ShPolymer}_{\mathrm{truck_{tires}}}\left[\frac{kg\ microplastics}{kg\ tread}\right]\end{aligned}$$

For this calculation, the parameters in Table 8-3 apply.

Table 8-3: Parameters for calculating tread losses for transport of goods by truck

Abreviation	Description	Unit	Generic value if available	Reference
$\mathrm{TireLoss}_{truck\_tot}$	Losses of microplastics related to tire tread abrasion on road surfaces for transport of goods by truck	kg (microplastics)	n/a (to be calculated)	n/a
D_{truck_vhc}	Distance travelled by the truck	vhc*km	n/a (primary data to be provided)	n/a
D_{truck_prod}	Distance over which the products are transported	km	n/a (primary data to be provided)	n/a
M_{prod}	Mass of products transported over D_{truck_prod}	kg	n/a (primary data to be provided)	n/a
Load_{av}	Average load from trucks in the country	kg	Medium and heavy trucks : 12'000 Light trucks : 3'500	Expert judgment
$\mathrm{Loss}_{truck\_tires}$	Loss of tire tread per kilometer travelled by the vehicle	kg (tread) / (vhc*km)	See Table 8-5	Literature review (see Appendix D)
$\mathrm{ShPolymer}_{truck\_tires}$	Share of polymer (synthetic rubber + natural rubber) in tire tread	kg (microplastics)/ kg (tread)	See Table 8-6	ETRMA (data provided May 29, 2019)

Passenger transport by plane

The equation for calculating tire tread losses of transport by a plane is the following if the available data include the number of cycles “take-off, landing, taxing” by one or more aircraft:

$$\begin{aligned}\mathrm{TotTireLoss_{plane}}\ [kg\ microplastics] \\ = \mathrm{NbCycle}\ [\mathrm{cycle}] * \mathrm{Loss_{aircraft\_tires}}\left[\frac{kg\ tread}{cycle}\right] \\ * \mathrm{ShPolymer}_{aircraft\_tires}\ [\frac{kg\ microplastics}{kg\ tread}]\end{aligned}$$

OR:

If available data include the number of flights (i.e., cycles of “take-off, landing, taxiing”) of one or more passengers, the following equation shall be used:

$$\begin{aligned}\mathrm{TireLoss_{plane\_pass}}[kg\ microplastics] \\ = \frac{\mathrm{NbCycle}\ [\mathrm{cycle}] *\ \mathrm{Nb_{pass}}\ [pers]}{\mathrm{Pass_{av}}\ [pers/vhc]} *\ \mathrm{Loss_{aircraft\_tires}}\left[\frac{kg\ tread}{vhc * cycle}\right] \\ * \mathrm{ShPolymer_{aircraft\_tires}}[\frac{kg\ microplastics}{kg\ tread}]\end{aligned}$$

For this calculation, the parameters in Table 8-4 apply.

Table 8-4: Parameters for calculating tread losses for transport of passengers by plane

Abreviation	Description	Unit	Generic value if available	Reference
$\mathrm{TotTireLoss}_{\mathrm{plane}}$	Losses of microplastics related to tire abrasion on strip surfaces for transport by plane	kg (microplastics)	n/a (to be calculated)	n/a
$\mathrm{NbCycle}$	Number of cycles "take-off, landing, taxiing" for the travel	cycle	n/a (primary data to be provided)	n/a
$\mathrm{Nb}_{\mathrm{pass}}$	Number of passengers travelling over Nb Cycles	pers	n/a (primary data to be provided)	n/a
$\mathrm{Pass}_{\mathrm{av}}$	Average number of passengers per vehicle	Pers/vhc	110	4.1 billion passengers for 37 million departures https://www.air-journal.fr/2018-01-19-nouveau-record-avec-41-milliards-de-passagers-dans-le-monde-en-2017-5193395.html
$\mathrm{Loss}_{\mathrm{aircraft\_tires}}$	Loss of tire tread per cycle of "take-off, landing, taxiing"	kg (tread)/(vhc*cycle)	0.278 kg (tread)/vhc*cycle	(Kole et al. 2017)
$\mathrm{ShPolymer}_{\mathrm{aircraft\_tires}}$	Share of plastic (synthetic rubber + natural rubber) in tire tread	%	See Table 8-6	ETRMA (data provided 29 May 2019)

Parameters for the different types of vehicles

The parameters for the calculation of tread losses for the different vehicles are presented in the tables below.

Table 8-5: Loss of tire tread per kilometer for different types of vehicles for road transport (Source: Literature review presented in Appendix D)

Type of vehicle		$Loss_{vehicle\_tires}$ **Loss of tire tread per kilometer travelled by the vehicle** [mg (tread) / (vhc*km)]
Motorcycle	Motorcycle	45
	Scooter	45
Passenger car/light truck	Passenger car	102
	Light truck	142
Bus/coach	City bus	415
	Long haul coach	326
Medium/heavy truck	Medium/heavy truck long haul	517
	Medium/heavy truck short haul	658

Table 8-6: Share of polymer (synthetic rubber + natural rubber) in tire tread for different types of vehicles

Type of vehicle		$ShPolymer_{vehicle\_tire}$ **Share of polymer fraction (synthetic rubber + natural rubber) in tire tread** [kg (microplastics[14]) / kg (tread)]	**Range provided by ETRMA (2019)** [kg (microplastics) / kg (tread)]
Motorcycle	Motorcycle	0.40	0.30 to 0.50
	Scooter	0.50	ca. 0.50
Passenger car / light truck	Passenger car	0.35	0.34 to 0.38
	Light truck	0.36	0.34 to 0.38
Bus/coach	City bus	0.50	0.24 to 0.76
	Long haul coach	0.58	0.42 to 0.73
Medium/heavy truck	Medium/heavy truck long haul	0.60	0.51 to 0.68
	Medium/heavy truck short haul	0.50	0.35 to 0.65
Aircraft	Aircraft	0.53	0.50 to 0.55

Table 8-7: Average number of passengers per vehicle for road transport

Type of vehicle		$Pass_{av}$ **Average number of passenger(s) per vehicle vehicle** [Pers/vhc]	**Source**
Motorcycle	Motorcycle and scooter	1	Expert judgment
	Scooter	1	Expert judgment
Passenger car/light truck	Passenger car	1.6	Ecoinvent v2.2
	Light truck	1.6	Ecoinvent v2.2
Bus/coach	City bus	30	Süßmann & Lienkamp, 2015 (Chapter 2.1.3 and 2.1.4)
	Long haul coach	50	

[14] For the sake of consistency, the share of polymer is expressed as kg microplastics/kg tread instead of kg polymer/kg tread.

8.7.4 Calculation rules for tread losses for tire-related studies

For the tread losses involved in studies focusing on tires (e.g., plastic leakage assessment of a tire over its life cycle), the following calculation rules shall be applied to use data specific to the tire. The calculation rules presented in this document are the rules from the Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD) for the Product Category: Tires (2017-11-28).

The first rule is that companies shall use their own internal Computer Aided Design (CAD) tire mold modeling capabilities to determine the tire tread losses.

If it is not feasible to use CAD modeling, then the following equations shall be used to estimate tire tread losses over the lifespan of the tire[15].

$$\begin{aligned}\mathrm{TotTireLoss}\ [\mathrm{kg\ microplastics}] &= \frac{1}{1000} * ((\mathrm{Tread\ Depth\ [cm]} - \mathrm{TWI\ Height\ [cm]}) \\ &* \mathrm{Tread\ Length\ [cm]} * \mathrm{Density}[\frac{\mathrm{g}}{\mathrm{cm3}}] * (\mathrm{contact\ Width\ [cm]} \\ &* (1 - \mathrm{Void\ Ratio\ [-]}) + \alpha\ [\mathrm{cm}]) \quad * \mathrm{ShPolymer_{tire}}\ [\frac{kg\ microplastics}{kg\ tread}]\end{aligned}$$

Where:

$$\mathrm{Tread\ Length[cm]} = (2 * \mathrm{Outer\ Radius\ [cm]} - \mathrm{Tread\ Depth[cm]}) * \pi\ [-]$$

For this calculation, the parameters in Table 8-8 apply.

[15] Tire tread losses are determined by calculating the mass of tread compound above the Tread Wear Indicator (TWI) on the tire, based on the assumption that the tire is completely worn down to the TWI before being replaced. In many regions it is common practice to change tires before the TWI is reached, so that the actual amount of tread released into the environment is lower than what is calculated.

Table 8-8: Parameters for calculating tire tread losses for tire-related studies (Table from Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD) for the Product Category: Tires (2017-11-28))

AbBreviation	Description	Unit	Generic value if available	Reference
TotTireLoss	Losses of microplastics related to tire abrasion on road surfaces for one tire over its life cycle	kg (microplastics)/ tire	n/a (to be calculated)	n/a
Tread Depth	Average of the tread depth at each groove (measured from the top of the tread down to the treadwear indicator)	- cm	n/a (primary data to be provided)	n/a
TWI Height	Height of the treadwear indicator	cm	n/a (primary data to be provided)	n/a
Tread Length	Tread length as measured around the circumference of the tire at the center line	cm	n/a (primary data to be provided)	n/a
Density	Density of the tread compound	g/cm^3	n/a (primary data to be provided)	n/a
Contact Width	The flat portion of the tread that contacts the road; this can be obtained from the footprint measurement at 85% load	cm	As a proxy, can be estimated as “Tread Width of the original new tire”	Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD) for the Product Category: Tires
Void Ratio	Part of tread volume that does not contain rubber, from the tire engineering specification	[-]	n/a (primary data to be provided)	n/a
Outer Radius	Distance from the center of the rim to the top of the tire tread	cm	n/a (primary data to be provided)	n/a
α	Calculated as: ((Tread Width of the worn tire until Tread Wear Indicator) –	cm	if α is not calculated, these default values may be used:	Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD)

	(Tread Width of the original new tire))/2		• Passenger car and light truck tire: 2 cm • Medium/heavy truck tire: 0 cm Bus tire: 0 cm	for the Product Category: Tires
$ShPolymer_{tire}$	Share of polymer (synthetic rubber + natural rubber) in tire tread	kg (microplastics)/kg (tread)	n/a (primary data to be provided)	n/a

8.7.5 Calculation rules for initial release rates

The equations to calculate the global release rates $RelR_{ocean}$, $RelR_{frw}$, $RelR_{soil}$, $RelR_{terenv}$ $RelR_{ocean}$, and $RelR_{air}$ synthetic microfibers are presented in Figure 8.4 and below.

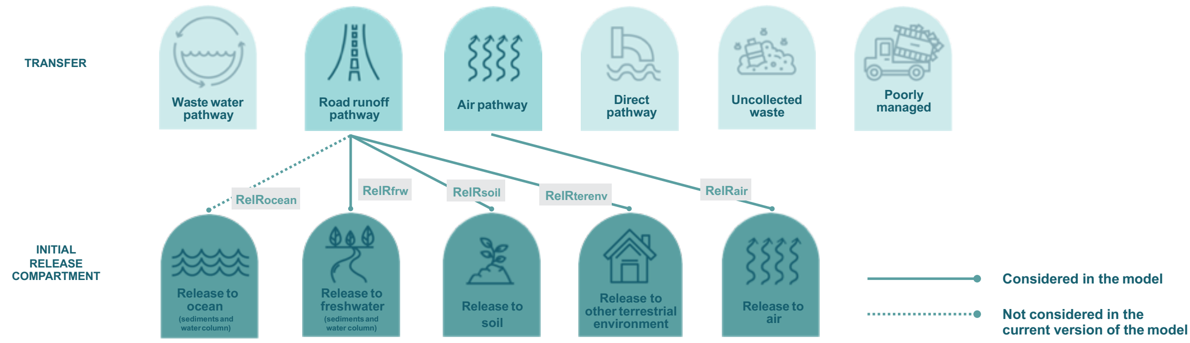


Figure 8.4: Release rates leading from the road runoff and air pathways to the initial release compartment for TRWP

The amount of TRWP culminating in the natural compartments depends on the type and efficiency of the wastewater treatment system in place. Below in Figure 8.5 is a detailed view of the pathways with the different sewer systems.

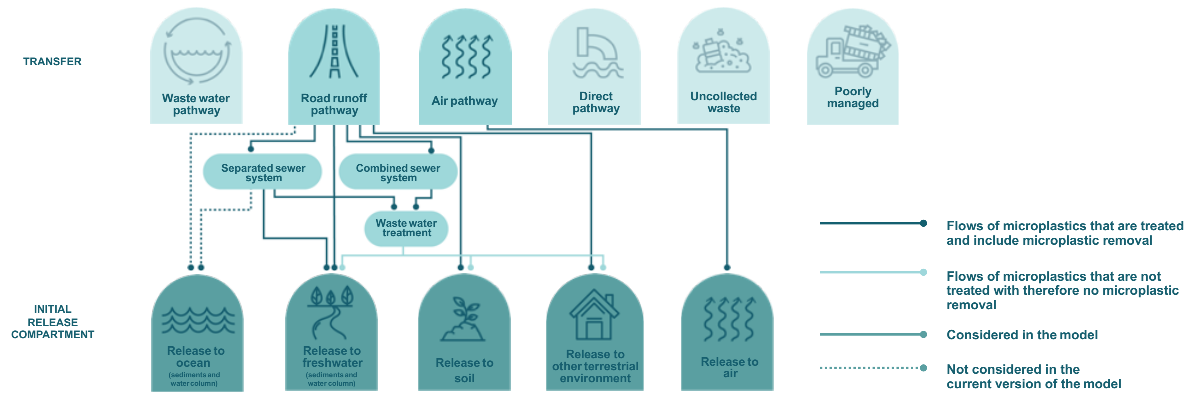


Figure 8.5: Detailed schematic of the road runoff pathway and water treatment.

First major distribution between the transfer pathways

The TRWP are distributed among three main transfer pathways, which are summarized in Table 8-9.

Table 8-9: First major distribution of TRWP

Type of road	To air[16]	To soil nearby[17]	To runoff water[17]
Rural	2%	83%	15%
Urban	2%	29%	69%
Highway	2%	39%	59%

Air emissions and initial compartments

$RelR_{air}$ represents the direct release of TRWP in the air. This concerns the smallest particles PM10 (below 10 μm). Estimates for the fraction of PM10 in the total mass of TRWP vary between 1% and 7% depending on the study (Unice et al. 2018). It was decided to use the value found in the most recent study (Unice et al. 2018), i.e., **2%.**

Near-road deposition and initial compartments

Near-road deposition concerns particles larger than 10 μm, and **soil** $(RelR_{soil1})$ is considered to be the initial compartment for near road deposition.

Transfer through runoff and initial compartments

The initial compartments for particles transferred through runoff depend on the type of road (rural, urban or highway), and on the type of sewer system in certain cases (urban road and highways only). This is due to the fact that combined sewer systems

[16] Unice et al. U2018)
[17] as suggested by Jos Van Gils, July 2018

direct all inflow to wastewater treatment plants, while separated systems lead rainwater directly to surface water18.

The default values chosen for the share of systems are summarized in the table below (Unice et al. 2018).

Table 8-10: Breakdown of initial compartment releases for runoff water, including into different sewer systems, direct to freshwater, storm water management systems or ditches

Type of road	Share separated sewage system[18] + no system (both flows go directly to freshwater) $(RelR_{frw1})$	Share combined sewage system	Retention in storm water management system	To ditches (goes directly to soil) $(RelR_{soil2})$
Rural	25%	0%		75%
Urban	25%	75%		
Highway	50%	0%	50%	

For the share of TRWP that is released to **combined systems**, the following parameters influence initial release rates:

Combined sewer system: wastewater treatment plant and efficiency of TRWP retention

a) For the TRWP going through a wastewater treatment plant, it is necessary to account for the efficiency of the treatment (retention rate of TRWP), which is correlated to the country. The default value chosen for retention of TRWP is 95%, with the remaining 5% being released to freshwater (Unice et al. 2018). This value can be adapted to model a scenario specific to a country/geographical area.

b) Combined sewer system: Combined Sewer Overflow (CSO)

For the TRWP moving through a combined system, it is necessary to include the water being released to CSO and eventually to freshwater $(RelR_{frw2})$. The default value chosen for CSO is 5% of TRWP moving through a combined system (Unice et al. 2018).

c) Combined sewer system: disposal of wastewater treatment sludge

[18] Separated systems lead rainwater either directly to surface water or a rainwater treatment system. However, due to a lack of data, it is estimated that rainwater going through separated systems is discharged directly into surface water (Unice et al. 2018).

For the TRWP going though wastewater treatment plants, the portion consolidated into sludge is then distributed among different initial compartment depending on the treatment of the sludge.

i) The sludge spread on fields is released in soils $(RelR_{Soil2})$. The default value chosen for the share of sludge being spread is 50% (source: average value for Europe from Carbonell et al. (2009); Bianchini et al. (2016) see Table 7-2 for more detailed information).

ii) The fraction of sludge not spread on fields is considered to be landfilled or incinerated, and therefore removed from the environment (there is currently no data for microplastic loss rates after deposition in landfill), except for the part that is mismanaged; this part is considered to be released into “other terrestrial environments” $(RelR_{terenv1})$. The default average for the mismanaged waste index is 10.7%[19] (Bianchini et al. 2016). This can be adapted to a specific country or to the values presented in section 14.

For the share of TRWP that is released **in storm water management systems (highways),** it is assumed that the sludge from storm water management systems is landfilled or incinerated and therefore removed from the environment (there is currently no data for microplastic loss rates after deposition in landfill), except for the part that is mismanaged; this part is considered to be released in “other terrestrial environments” $((RelR_{terenv2}) and\ (RelR_{terenv3}))$. The default average value for the mismanaged waste index is 10.7%19 (Bianchini et al. 2016). This can be adapted to a specific country or to the values presented in section 14.

Location and initial compartments

The location of the road has a strong influence on the type of surface water into which runoff water is discharged after leaving the sewer system; in coastal areas, runoff water is released into oceans, while in other areas runoff is released into freshwater.

[19] The value 10.7% for mismanaged waste for sludge not spread in fields is the fraction of sludge for which the treatment of sludge remains “unknown” (EU 27).

Limitations

Due to lack of data, especially on the proportion of road runoff flowing to freshwater versus oceans, in the current version of the guidance it is assumed that 100% of surface water to which runoff water is released is freshwater (and the sedimentation rate in freshwater is then applied – knowing that this sedimentation rate is from the Sein watershed).

This is a key limitation of this study, and the authors advocate for more research as well as encourage an update to the methodology when more data becomes available. Nonetheless, even if the current release rate of TRWP in oceans is underestimated, the sum of the release into freshwater (water column + sediments) and the release into oceans (water column + oceans) is not affected. This is therefore considered a robust estimate of the leakage of microplastics from tire abrasion in aqueous compartments (freshwater + oceans).

Types of roads and initial compartments

Calculations concerning the first major redistribution and the subsequent stages of runoff depend on the type of road. The default values allocating by road type used to calculate an average global scenario are shown in Table 8-11 (Unice et al. 2018).

Table 8-11: Share of road type (100% is the total amount of road)

Type of road	Share per type of road
Rural	40%
Urban	33%
Highway	27%

Initial release rates

The initial release rate into various initial compartments are presented in Table 8-12. These initial release rates are expressed as a percentage of TRWP emitted. The same percentages can be applied to losses of microplastics from tire abrasion to calculate microplastic leakages from tire abrasion.

The detailed calculation of initial release rates is provided in the data repository in the file *PLP_Sectorial_Guidances_Generic_data* where specific parameters can be adapted to reflect specific conditions.

Table 8-12: Initial release rates

ABbreviation	Description	Generic value [% of TRWP emitted], or [% of microplastic from tire abrasion]	Detailed description
$RelR_{oceans}$	Release rate of TRWP in ocean compartment	**0%**	TRWP released into oceans[20]
$RelR_{air}$	Release rate of TRWP in air compartment	**2%**	TRWP emitted as dust in the air
$RelR_{\mathrm{frw}}$	Release rate of TRWP in freshwater compartment	**17%**	TRWP in runoff water going though separated system and directly released in freshwater TRWP in runoff water going through CSO of combined system TRWP in runoff water going through combined system but not retentate in wastewater treatment plant
$RelR_{soil}$	Release rate of TRWP in soil compartment	**66%**	TRWP deposited near road TRWP in runoff water going through combined system, retentate in wastewater treatment plant and sludge is spread on fields TRWP retentate in ditches
$RelR_{terenv}$	Release rate of TRWP in other terrestrial compartments	**2%**	Mismanaged waste from TRWP retentate in WWTP sludge not spread Mismanaged waste from TRWP retentate in storm water management sludge
Well managed waste	Part of TRWP that is removed from the environment	**14%**	TRWP retentate in WWTP sludge not spread that is landfilled or incinerated TRWP retentate in storm water management, sludge that is landfilled or incinerated

[20] The share of TRWP being released to the ocean through runoff in coastal areas is not included, due to a lack of data.

8.7.6 Calculation rules for redistribution rates

The equation to calculate the redistribution rate $RedR$ is presented in Figure 8.6 and below.

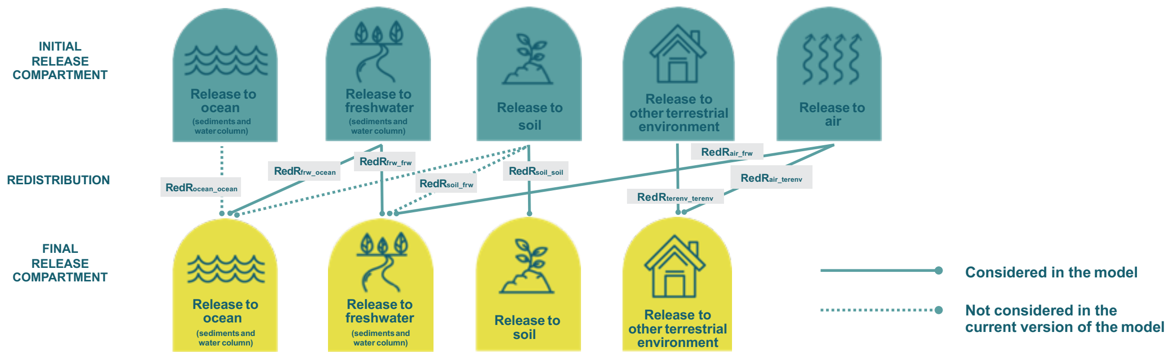


Figure 8.6: Redistribution rates for microplastics

Redistribution of TRWP released initially to ocean

It is assumed that all TRWP released to oceans remain in oceans.

$$RedR_{ocean\_ocean} = 100\%$$

Redistribution of TRWP released initially to freshwater

It is assumed that TRWP released to freshwater are partly retained in freshwater sediments and partly released into oceans. The ratio of TRWP captured in freshwater sediments $R_{freshsed}$ is used to calculate $RedR_{frw\_ocean}$ and $RedR_{frw\_frw}$.

$$RedR_{frw\_ocean} = 1 - R_{freshsed}$$

$RedR_{frw\_frw} = R_{freshsed}$ As explained in section 8.6, several parameters can influence the sedimentation rate of particles released to freshwater. However, at the time of our study only a single study proposed a robust and accurate value for sedimentation rate, and no data were available to account for the influence of hydrology, meteorological conditions and local specificities (coastal area or continental area).

As a preliminary proxy, the default value proposed for sedimentation rate $R_{freshsed}$ is 90%[21] as proposed in Unice et al. (2018), i.e., **90% of TRWP released in freshwater is deposited in freshwater sediments.**

Limitations

The lack of data for sedimentation rate of TRWP in coastal areas is one of the limitations of the PLP guidelines. The two publications used to support sedimentation rates for the other sectoral guidelines (i.e., textiles and packaging) were not germane for TRWP:

- In Jambeck et al. 2015, "coastal area" was defined as any area within 50 km of the sea. However, the so-called "coastal areas" might be representative for macro-plastics (or microplastics of low density that remain within the water column), but these areas cannot be representative for TRWP, which have a high density and therefore settle quickly.
- In Siegfried et al. 2017, two sedimentation rates were proposed to account for release, regardless of distance to sea: 75% for small watersheds and 90% for large watersheds. However, the authors estimate that these figures would be applied to non-associated fraction of SBR (i.e., tire tread not embedded with road pavement), and suggest that otherwise the sedimentation rate of TRWP would be 100%. In addition, the value for TRWP density is estimated to be 1.2 to 1.3 g/cm^3, which corresponds to tread density. As a consequence, this publication was deemed not applicable.

Due to the lack of data to estimate such an uncertain value, the influence of coastal area on redistribution of TRWP is not treated in the current version of the PLP guidelines.

This is a high priority area for improvement in a future version of the guidelines.

[21] It should be noted that the value 90% calculated in Unice et al. (2018) refers to the portion of TRWP reaching estuaries. However, since no better data are available, it is a preliminary assumption that reaching the estuaries is tantamount to reaching the ocean.

Redistribution of TRWP released initially to soil

It is considered that TRWP released to soils are **100% retained in soils**. In fact, Unice et al. (2018) demonstrated that only 0.01% of TRWP released to soils are redistributed to freshwater due to soil erosion. For simplification, soil erosion with a possible redistribution in other final compartments is not considered at this stage of the study.

$$RedR_{soil\_soil} = 100\%$$

Redistribution of TRWP released initially to air

As explained in section 8.6, the TRWP emitted into air are considered to be completely washed away by rainwater and deposited in other compartments (e.g., soil, freshwater) since they do not degrade in the air.

Residence time in air

As for the initial release in other compartments, the TRWP stays in the air for a few days before being washed out, given that its density is greater than air. This is why air is not considered as a final release compartment. However, there will be a resulting air concentration and an exposure associated with the average residence time of PM10 in the air, which might be taken into account for the subsequent stage of estimating the impacts resulting from plastic leakage. The estimation of the residence time in each environmental compartment is indeed key to fate and exposure modelling, which is a first step leading to a full impact assessment indicator. For the plastic leakage inventory metric, we consider 100% of microplastics will be deposited at one point (on land, ocean, etc.), though they might change size[22]. Allen et al. (2019b) even suggest that microplastics can be transported over 100 km by the wind, from cities to remote areas such as Pyrenean mountains.

As an initial proxy, assuming redistribution[22] based on surface area, redistribution to oceans can be excluded since there are few emissions occurring over the ocean. Furthermore, there is limited evidence that TRWP emitted above land and waterways are transported to the ocean. As a consequence, it is estimated that TRWP released into air are redistributed to other terrestrial environments[23] and freshwater. Based on FAO Agri-Environmental Indicators/Land cover[24], inland water bodies correspond to 3% of the surface area. **As an initial proxy, default values for redistribution are that 3% of air emissions are deposited into freshwater, and 97% into other terrestrial environments.**

$$RedR_{air\_terenv} = 97\%$$

$$RedR_{air\_frw} = 3\%$$

Redistribution of TRWP released initially to other terrestrial environments

It is considered that all TRWP released to other terrestrial environments remain in oceans.

$$RedR_{terenv\_terenv} = 100\%$$

[22] Based on personal exchanges with Olivier Jolliet, Professor in Impact & Risk Modeling (iMod), University of Michigan, School of Public Health, Dept. of Environmental Health Sciences
[23] The compartment "other terrestrial environment" is used instead of "soils" since particles can be deposited on soils, but also on trees, buildings, etc, which are defined as "other terrestrial environment"
[24] FAO Agri-Environmental Indicators / Land cover, available at http://www.fao.org/faostat/en/#data/LC

8.7.7 Leakage and final release rates

The leakage of microplastics $Leak\_micro$ is ultimately calculated as the sum of the microplastic loss from tire abrasion ($\mathrm{TotTireLoss}$), multiplied by the release rates ($RelR$) and the redistribution rates ($RedR$) in each specific environmental compartment.

$$Leak\_micro_{oceans} = \sum(\mathrm{TotTireLoss} * RelR_{frw} * RedR_{frw\_ocean})$$

$$Leak\_micro_{freshwater} = \sum(\mathrm{TotTireLoss} * (RelR_{frw} * RedR_{frw\_frw} + RelR_{air} * RedR_{air\_frw}))$$

$$Leak\_micro_{soils} = \sum(MiPL * RelR_{soil} * RedR_{soil\_soil})$$

$$Leak\_micro_{terenv} = \sum(MiPL * RelR_{terenv} * RedR_{terenv\_terenv} + RelR_{air} * RedR_{air\_terenv}))$$

To simplify the approach, the final release rates in the final environmental compartments (calculated as initial release rates ($RelR$) multiplied by the redistribution rates ($RedR$)) can be directly applied to the loss from tire abrasion, and are presented in Table 8-13.

These final release rates are expressed as a percentage of the TRWP emitted. The same percentages can be applied to the losses of TRWP from tire abrasion specifically, to calculate the polymer content of the TRWP from tire abrasion.

The detailed calculations of final release rates are provided in the data repository in the file PLP_Sectorial_Guidances_Generic_data.

Table 8-13: Final release rates

Abbreviation	Description	Generic value [% of TRWP emitted], or [% of microplastics from tire abrasion]	Detailed description
$FinalRelR_{ocean}$	Final release rate of TRWP in ocean (sediments and water column) compartment	**2%**[25]	TRWP emitted in freshwater initial compartment and not deposited into sediments
$FinalRelR_{air}$	Final release rate of TRWP in air compartment	**0%**	TRWP redistributed to freshwater and other terrestrial environment compartments
$FinalRelR_{frw}$	Final release rate of TRWP in freshwater (sediments and water column) compartment	**15%**	TRWP deposited in freshwater sediments, coming from: - TRWP in runoff water going though separated system and directly released in freshwater - TRWP in runoff water going through CSO of combined system - TRWP in runoff water going through combined system but not retentate in wastewater treatment plant

[25] Please note that this value does not include TRWP released to the ocean through runoff in coastal areas, due to lack of data.

$FinalRelR_{soil}$	Final release rate of TRWP in soil compartment	**66%**	TRWP captured in soil, coming from: - TRWP deposited near roads - TRWP in runoff water going through combined system, retentate in wastewater treatment plant and from which sludge is spread on fields - TRWP retentate in ditches
$FinalRelR_{terenv}$	Final release rate of TRWP in other terrestrial compartments	**4%**	Mismanaged waste from TRWP retentate in WWTP sludge not spread Mismanaged waste from TRWP retentate in storm water management sludge TRWP initially released into air redistributed between freshwater and other terr. compartments
Well managed waste	Part of TRWP that is removed from the environment	**14%**	TRWP retentate in WWTP sludge not spread that is landfilled or incinerated TRWP retentate in storm water management sludge that is landfilled or incinerated

8.8 Sensitivity analysis

A sensitivity analysis should be performed to test parameters which have a high impact on the final leakage and/or high uncertainty. The loss rates calculated based on literature review (average) should be tested with the low and high loss rate values that are presented in Table 8-14.

Table 8-14: Loss of tire tread for different types of vehicles for road transport: low, median and high values (Source: literature review presented in Appendix D)

		$Loss_{vehicle\_tires}$ **Loss of tire tread, in mg per kilometer travelled by the vehicle** [mg (tread) / (vhc*km)]		
Type of vehicle		**low (1st quartile)**	**median**	**high (3rd quartile)**
Motorcycle	Motorcycle	39	45	47
	Scooter	39	45	47
Passenger car/light truck	Passenger car	93	102	129
	Light truck	119	142	170
Bus/coach[26]	City bus	n/a	415	n/a
	Long haul coach	n/a	325	n/a
Medium/heavy truck	Medium/heavy truck long haul	495	517	600
	Medium/heavy truck short haul	517	658	1068

[26] At the time of the current version of the PLP guidelines, no other relevant data were available in the literature to fix a low and high value for sensitivity analysis on bus loss rates.

Inventory of microplastic leakage from plastic production

9

9.1 Introduction

Companies manufacturing plastic goods use feedstocks of plastic materials which are melted and formed into plastic products. The feedstock typically consists of small pellets, although flake and powder forms are sometimes used: however, literature and data often do not distinguish between these forms of raw material. Flake and powder are therefore assumed to be included within this analysis, even though they are not explicitly investigated. According to Hann et al. (2018), this assumption is reasonable, given that pellets are the most common form of plastic raw material in Europe.

Pellets are a form of primary microplastic defined in ISO 472:2013 as a "small mass of preformed molding material, having relatively uniform dimensions in a given lot, used as feedstock in molding and extrusion operations". They are usually spherical or cylindrical, approximately 5 mm in diameter (Alison et al. 2015).

9.2 System map for the leakage of microplastics from plastic production

Current research on pellet loss focuses on pellets entering drains at or near plastics facilities. We are aware that losses in other areas may occur, such as in grassy areas and at the periphery of plastics facilities. However, we conservatively include losses only to drains, due to a lack of published research on losses in other areas. Figure 9.1 represents the general methodological principles to account for plastic leakage to the environment as applied to pellets.

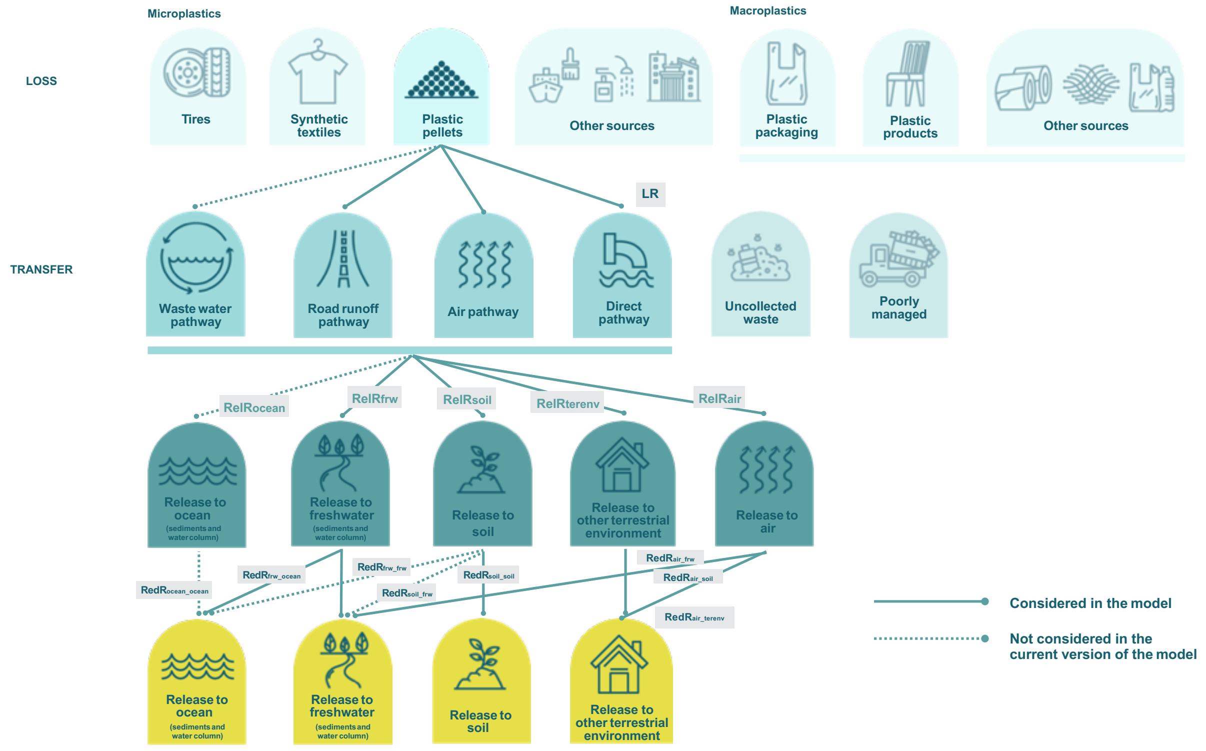


Figure 9.1: Losses, transfer pathways and plastic release compartments for pellets

9.3 Calculation rules

9.3.1 Calculation rules for loss rates

In these guidelines, the term 'pellet loss' refers to pellets that are spilled but not recovered, and thus enter the environment. It does not refer to all pellets 'lost' from the manufacturing process, which would include pellet waste that is properly contained and disposed of.

It is widely recognized in studies on pellet loss that pellets may be spilled and lost at any point in the plastics value chain: at compounders, masterbatch makers, distributors, resellers, storage locations, processors, recyclers, during waste management, at ports and when being transported between each of these points. The greater the number of points at which pellets are handled, the greater the opportunities for loss. According to Hann et al. (2018), pellets typically arrive at sites in three different types of packaging container: in bulk tankers, in boxes on a pallet, and in 25 kg bags.

- When pellets are transported through bulk tankers to processing sites, a vacuum system is used to transfer pellets from the tanker to the silo through a hose. The most common point for spillage is when connecting or disconnecting the pipework to the tanker or the silo. Both the tanker and the silo are typically in an outside area.
- Boxes and bags are handled with forklift trucks, either on pallets or moved individually, so there is a much greater risk of spills and loss than when pellets are delivered in a tanker.

Based on Hann et al. (2018) and Cole and Sherrington (2016), the figures for pellet loss at processors of 0.04% (according to Sundt et al. (2014)) and 0.001% - 0.01% (based on Lassen et al. (2015)) would appear to be the most reliable. Unfortunately, these estimates also have their limits. The figure based on Sundt et al. (2014) is an estimate from just one processor and is not based on direct measurement. The Lassen et al. (2015) study is based on estimates from several processors but was not directly measured, either. Additionally, the Lassen (2015) study represents OCS (Operation Clean Sweep®)[27] facilities which may contain pellets better than most: the Lassen et al. (2015) study assumes that the average facility loses ten times more than the best performing. The figures for pellet loss at processors are assumed to be the same for all the steps of the value chain from Hann et al. (2018), except transportation s. Table 9-1 shows estimates of the losses of pre-production plastics.

[27] https://www.opcleansweep.org/

Table 9-1: Estimates of the losses of pre-production plastics.

	Description	Loss rate/leakage in the environment	References
Production	Producers create polymers and extrude resin pellets from powders or liquids. Spills occur during handling, loading and unloading, as well as leakage from containers and storage silos.	0.01% - 0.04%	Lassen et al. (2015) Sundt et al. (2014) Cole and Sherrington (2016)
Transportation	Transport includes loading and unloading, accidental loss from railcars, trucks and shipping containers (due to unsuitable packaging, spills and so on) that transfer pellets from producers to processors. This estimate is based on an average transportation distance between the plastic pellets production plant and the plastic processing plant.	0.001%-0.002%	Hann et al. (2018),
Processing	Processors (or converters), which melt and remold plastic pellets (usually compounds) into final plastic products. Spills occur during handling, loading and unloading, as well as leakage from containers and storage silos.	0.01% - 0.04%	Lassen et al. (2015) Sundt et al. (2014) Cole and Sherrington (2016)
Waste management	Management of producers and processors' waste: pellet loss mostly occurs during storage for disposal when pellets are either disposed of with mixed residual waste or blown away from bins stored outside.	0.01% - 0.04%	Lassen et al. (2015) Sundt et al. (2014) Cole and Sherrington (2016)
Recycling	Recyclers, which sort, clean and process waste plastics (predominantly packaging) into recycled plastic pellets and compounds.	0.01% - 0.04%	Lassen et al. (2015) Sundt et al. (2014) Cole and Sherrington (2016)
Suppliers	Logistics suppliers, providing intermediary services to the stakeholders above, aside from transporters i.e., including warehousing, redistribution, packaging etc. These intermediary points are important as they represent additional stages at which pellets are handled and can therefore be lost.	0.01% - 0.04%	Lassen et al. (2015) Sundt et al. (2014) Cole and Sherrington (2016)

By summing each stage reported in Table 9-1, we calculate values ranging from 0.0051% to 0.2020%. From this calculation we derive the orders of magnitude for pellets loss rates to range from 0.001% to 0.1%. Given this high uncertainty we suggest using these orders of magnitude rather than the exact values to avoid presenting a false sense of precision. Due to this high uncertainty and the large influence that this value may have on the final results, it is recommended to use a value with an average order of magnitude of **0.01%.**

9.3.2 Calculation rules for release and redistribution rates

Release and redistribution rates of pellet losses in the different compartments are assumed to follow similar routes to microplastics from tire abrasion, except for the value of retention rate for freshwater sediments set to 30% based on Hurley et al. (2018).

A retention rate of 30% for river sediments is assumed. Hurley et al. (2018) demonstrated that flooding carried away approximately 70% of the microplastic load stored on river beds, thus microplastic contamination is efficiently flushed from river catchments during flooding. This preliminary estimate can be refined by performing a wider literature review. This value has a high uncertainty given that the retention rate of plastic pellets in freshwater sediments depends on the plastic polymer density and other parameters.

A retention rate of 100% for soil is assumed. As demonstrated by Nizzetto et al. (2016a), large microplastic particles (> 0.2 mm) are more likely to be retained by soils. Plastic pellets have a diameter of approximately 5 mm and are thus considered to have a similar retention rate in soils to TRWP, as an initial approximation.

The leakage calculation is based on the equations mentioned in sections 8.7.5, 8.7.6 and 8.7.7, except that the redistribution rates use a different retention rate for river sediments.

For the calculation of these rates, please refer to Section 8 and to the file *PLP_Sectorial_Guidances_Generic_data*.

9.4 Sensitivity analysis

A sensitivity analysis should be performed to test parameters that have a strong influence on the final leakage and/or high uncertainty. Due to the high uncertainty of pellet loss rates, it is recommended to do a sensitivity analysis with the highest (0.1%) and lowest (0.001%) values of the range provided above.

Guideline limitations

10

Key limitations of the methodology and the underlying data are listed in the following paragraph. They include structural limitations (hereafter "scope limitations") and parametric limitations (hereafter "data limitations"). This first iteration of methodology and model development prioritizes breadth and completeness thus yielding a wide-reaching model of which the principal shortcomings stem from lack of data to quantify all modeling stages. The main scope limitations are viewed as future improvements, especially with regard to evolving from inventory to impact assessment. The data limitations are listed in a subsequent table (Table 10-1) and should help the scientific community prioritize research efforts to improve the robustness of plastic leakage assessment.

- **Scope limitations:** The PLP methodology includes **scope limitations,** i.e., gaps in the assessment of some leakage sources due to lack of data. Assessments covered by this guidance and those not included are summarized in Table 4-1. Indeed, several leakage routes have been excluded, such as (but not limited to) macroplastics from fishing devices lost at sea, agricultural plastics leaked during use, microplastics leaked from cosmetics, construction material leaks, turf and artificial grass microparticle losses, road marking losses, and building and shipping paint. However, if a specific product or corporate activity is expected to have significant leakages not covered in these guidelines (e.g., microbeads for a cosmetic product), its plastic leakage assessment should include these leakage routes anyway, by collecting specific data, to ensure the plastic leakage results are not missing a potentially significant route.
- This methodology does not account for the generation and leakage of secondary microplastics.
- The model does not aim to calculate a steady-state concentration, but rather the initial and final release compartments of a quantity of plastic. The residence time in each compartment should be calculated when addressing impact assessment.
- This methodology includes "partial fate" in the mandatory plastic leakage metric, i.e., it includes redistribution from initial compartments to final compartments. Plastic degradation (i.e., total mineralization) is included as an optional metric for which generic degradation rates are not systematically provided.

Data limitations

The PLP methodology also includes generic data limitations, where the supporting data has high uncertainty and can be improved in the future as the state of the art develops.

Table 10-1 summarizes the key limitations of the gathered generic data. The use of specific data available for a product or corporate activity can overcome these limitations and strengthen the robustness of a plastic leakage assessment.

Utilization of the guidelines

Given the state of data accuracy and data quality used in the current version of the guidelines, the authors acknowledge that the current methodology mainly enables users to identify hotspots among the value chain rather than do comparative assessment.

Table 10-1: Key limitations for generic data supporting each plastic leakage route

<table>
<tr><th>Plastic leakage assessment route</th><th>Loss rate</th><th>Release rate</th><th>Redistribution rate</th></tr>
<tr><td>Macroplastic leakage from plastic waste</td><td>• Waste imports and exports should be integrated in the mismanaged waste rates
• End-of-life treatment based on a single source (World Bank 2018) should be refined
• Littering rate matrix based on expert judgment should be refined</td><td>• Release rate matrix based on expert judgment should be refined</td><td>• The redistribution rate of plastic released in terrestrial environment should be refined by considering plastics carried to lakes and oceans, e.g., by wind or birds</td></tr>
<tr><td>Microplastic leakage from textiles</td><td>• Considered as quite reliable given the estimate is based on a wide literature review. These data from literature can be reused more specifically for different types of textiles (e.g., knit vs. fleece, polyester vs. other polymers)</td><td>• Considered as quite reliable given the parameters are based on literature references. Some parameters can be adapted to a specific country context (e.g., SS_{agsoil} the share of sludge applied on agricultural soil, $SS_{mismanaged}$ the share of sludge that is mismanaged)</td><td>• The ratio of synthetic microfibers captured in freshwater sediments $R_{freshsed}$, the ratio of synthetic microfibers captured in soil R_{soil} and the redistribution from terrestrial environment $RedR_{terenv\_terenv}$ should be refined</td></tr>
<tr><td rowspan="2">Microplastic leakage from tire abrasion during transport</td><td rowspan="2">• Considered as quite reliable given the similarity of values found in the literature review.
• However, the influence of parameters is not captured (e.g., tire design, type of road, driving behavior, external temperature)</td><td>• No differentiation made between continental (large watersheds) and coastal areas, the latter for which runoff water is actually released to oceans and not to freshwater
• The distribution of runoff water released between freshwater (direct), sewer systems or CSO is representative of EU, as well as retention rate in WWTP</td><td>• Value for sedimentation rate in freshwater only representative of a specific geographical and hydrological context
• No value for redistribution in soils</td></tr>
<tr><td colspan="2">• The model does not take into account different factors (e.g., hydrologic and meteorological conditions, size and density of particles) on the distribution of TRWP, due to a lack of data</td></tr>
<tr><td>Microplastic leakage from plastic production</td><td>• Plastic pellet loss rates have an uncertainty of several orders of magnitude and should be refined when more literature data are available</td><td>• That the release rate is indifferent to environmental compartments is purely hypothetical and should be refined when more literature data is available</td><td>• Same remark as for the redistribution rate</td></tr>
</table>

Glossary

11

11.1 Plastic-related terms

11.1.1 Plastic

Plastics are commercially-used materials made from monomers and other raw materials chemically reacted to a macromolecular structure, the polymer, which forms the main structural component of the plastic.

The name plastic refers to their easy processability and shaping (in Greek: plas-tein = to form, to shape). Plastics are usually divided into two groups according to their physical or chemical hardening processes: thermoplastic and thermosetting resins (polymers). Plastics contain additives to achieve defined properties.

Sources: Elias, H. G., 2003. An introduction to plastics. Ed. Weiheim. https://eur-lex.europa.eu/eli/reg/2011/10/oj

11.1.2 Polymer

Polymers are a group of organic, semi-organic, or inorganic chemical substances containing large polymer molecules. These molecules are formed by linking together small molecules, called monomers, by polymerizations processes (in Greek: polys = many, meros = part). According to the International Union of Pure and Applied Chemistry (IUPAC) *polymer* and *macromolecular substance* are synonyms.

Source: Elias, H. G., 2003. An introduction to plastics. Ed. Weiheim.

11.1.3 Additive

Additives are chemical compounds added (e.g., during shaping of the polymer, through injection molding, extrusion, blow molding, vacuum molding) to improve the performance, functionality, and ageing properties of the polymer. The most commonly used additives in polymeric packaging materials are plasticizers, flame retardants, antioxidants, acid scavengers, light and heat stabilizers, lubricants, pigments, antistatic agents, slip compounds and thermal stabilizers. Each additive plays a distinct role in delivering/enhancing the functional properties of a plastic product.

Release of additives to the surrounding environment is an undesirable side effect for both the manufacturer and the environment, since loss of additives diminishes polymer attributes, and their presence in the environment harms living organisms.

Sources:

Hahladakis, J. N., et al., 2018. An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials 344, 179–199. https://doi.org/10.1016/j.jhazmat.2017.10.014

Teuten, E., 2009. Transport and release of chemicals from plastics to the environment ad to wildlife. Philosophical Transactions of the Royal Society B: Biological Sciences (2009) 364, 2027–2045 https://doi:10.1098/rstb.2008.0284.

11.1.4 Thermoplastic

Thermoplastics are defined as polymers that can be melted and recast almost indefinitely. They are molten when heated and harden upon cooling. When frozen, however, a thermoplastic becomes glass-like and subject to fracture. These characteristics, which lend the material its name, are reversible, so the material can be reheated, reshaped, and frozen repeatedly. As a result, thermoplastics are mechanically recyclable. Some of the most common types of thermoplastic are polypropylene, polyethylene, polyvinylchloride, polystyrene, polyethylene theraphthalate, and polycarbonate.

Source : https://www.plasticseurope.org/en/about-plastics/what-are-plastics/large-family

11.1.5 Thermoset polymer

Thermosetting, or thermoset, plastics are synthetic materials that undergo a chemical change when they are treated, creating a three-dimensional molecular network. After they are heated and formed, they cannot be remelted and reformed. Polyurethane, epoxy resin and Bakelite are typical examples of thermosetting plastic.

Source : https://www.plasticseurope.org/en/about-plastics/what-are-plastics/large-family

11.1.6 Bio-based plastics

Bio-based plastics are made wholly or partially from renewable biological resources. Bio-based plastics are a wide range of plastics (bio-PE, bio-PET, PLA, PHA, TPS, etc.) today produced mainly from resources such as sugar cane, sugar beets, wheat and corn. Properties, potential recycling and end-of-life options of bio-based plastics vary considerably from material to material. Bio-based plastics can be distinguished from fossil-based plastics by 14C analysis.

Source: https://www.european-bioplastics.org/bioplastics/

11.1.7 Biodegradable plastic

Biodegradable plastics are a family of plastics that can biodegrade (be decomposed by microorganisms into water, carbon dioxide and biomass) in a specific environmental compartment (such as soil, marine, freshwater) or a man-made environment (industrial or home composting).

Source: https://www.european-bioplastics.org/bioplastics/

11.1.8 Oxo-degradable plastic

So-called oxo-plastics or oxo-degradable plastics are conventional plastics that include additives to accelerate fragmentation into very small pieces, triggered by UV radiation or heat exposure. With these additives, plastics fragment over time into plastic particles, and finally microplastics, with properties similar to microplastics originating from the fragmentation of conventional plastics.

It is unproven as yet if this accelerated fragmentation also accelerates biodegradation. The question is whether plastic fragments undergo partial or full biodegradation within a reasonable time frame in the open environment, in landfills, or in a marine environment. If not, then oxo-degradable plastic contributes to microplastics release in the (marine) environment while misleading consumers. Furthermore, it is also unclear how additives affect plastic behavior in the environment and whether they have a toxic effect. Oxo-degradable plastics should not be considered as biodegradable or compostable plastics. EU will most likely ban oxo-plastics in coming years.

Source: REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL on the impact of the use of oxo-degradable plastic, including oxo-degradable plastic carrier bags, on the environment. 2018. http://ec.europa.eu/environment/circular-economy/pdf/oxo-plastics.pdf

11.1.9 Compostable plastic

Composting is enhanced biodegradation under managed conditions, predominantly characterized by forced aeration and natural heat production resulting from the biological activity taking place inside the material. The resulting material, compost, contains valuable nutrients and may improve soils.

Industrial composting requires elevated temperatures (55-60°C) combined with high relative humidity and the presence of oxygen, and it is optimal compared to other everyday biodegradation conditions, i.e., in soil, surface water and marine water. Compliance with EN 13432 is considered a desirable norm for industrial composting of packaging materials, e.g., biodegradable plastics. According to the EN 13432 standard, plastic packaging can be called compostable only if:

• the packaging material and its relevant organic components (>1 wt.%) are naturally biodegradable

• disintegration of the packaging material takes place in a composting process for organic waste within a certain time

• the packaging material has no negative effect on the composting process, and

• the quality of the compost is not negatively influenced by the packaging material

Source:

M. van den Oever, Bio-based and biodegradable plastics – Facts and Figures, Rapport nr. 1722, 2010

http://ec.europa.eu/environment/circular-economy/pdf/oxo-plastics.pdf

EN13432 : https://www.boutique.afnor.org/norme/nf-en-13432/emballage-exigences-relatives-aux-emballages-valorisables-par-compostage-et-biodegradation-programme-d-essai-et-criteres-d-e/article/726060/fa049121

11.1.10 Virgin plastic

A virgin plastic is a plastic made from virgin raw material, i.e., the extraction of crude oil. The term “primary” is often used interchangeably with “virgin”.

11.1.11 Recycled plastic

Recycled plastic is a plastic made from recovered and recycled material. The term “secondary” is often used interchangeably with “recycled”.

11.1.12 Primary/secondary/tertiary recycling

Table 11-1 shows different terminologies used in different types of plastic recycling and recovery.

Table 11-1: Terminology used in different types of plastic recycling and recovery

ASTM D5033 definitions	Equivalent ISO 15270 definitions	Other equivalent terms
Primary recycling	Mechanical recycling	Closed-loop recycling
Secondary recycling	Mechanical recycling	Downgrading
Tertiary recycling	Chemical recycling	Feedstock recycling
Quaternary recycling	Energy recovery	Valorization

Feedstock recycling, also known as chemical recycling or tertiary recycling, aims to convert polymer waste into original monomers or other valuable chemicals. These products are useful as feedstock for a variety of downstream industrial processes and as transportation fuels.

<u>Source</u> : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2873020/

11.1.13 SPI code

In 1988 The Society of the Plastics Industry (SPI) created a coding system that assists recyclers with recycling of plastics. Nowadays virtually all plastic products have a recycling symbol. The number inside the triangle indicates the type of synthetic resin:

Resin Identification Number	Resin	Resin Identification Code –Option A	Resin Identification Code –Option B
1	Poly(ethylene terephthalate)	1 PETE	01 PET
2	High density polyethylene	2 HDPE	02 PE-HD
3	Poly(vinyl chloride)	3 V	03 PVC
4	Low density polyethylene	4 LDPE	04 PE-LD
5	Polypropylene	5 PP	05 PP
6	Polystyrene	6 PS	06 PS
7	Other resins	7 OTHER	07 O

Figure 11.1: Resin identification number for plastics

11.1.14 Polyolefin

Polyolefins are a family of polyethylene and polypropylene thermoplastics, produced mainly from oil and natural gas, by a process of polymerization of ethylene and propylene respectively. Their versatility makes them one of the most popular plastics in use today.

There are four types of polyolefins: LDPE (low-density polyethylene), LLDPE (linear low-density polyethylene), HDPE (high-density polyethylene) and PP (polypropylene).

Source : https://www.plasticseurope.org/en/about-plastics/what-are-plastics/large-family

11.1.15 Single-use plastic

Single-use plastic products include a diverse range of commonly used fast-moving consumer products that are discarded after being used once for the purpose for which they were provided, rarely recycled, and often littered.

Source :

Council of the European Union (2019) DIRECTIVE (EU) 2019/... OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of on the reduction of the impact of certain plastic products on the environment. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_5483_2019_INIT&qid=1554217975397&from=EN

11.1.16 On-the-go vs in-home plastics

On-the-go plastic items are those consumed while on the move in public spaces, whereas in-home plastics are used in homes and cafes and restaurants.

Source :

http://www.seas-at-risk.org/images/pdf/publications/SeasAtRiskSummarysingleUseplasticandthemarineenvironment.compressed.pdf

11.1.17 Plastic detachable part

Any part of packaging that can be removed to access the product or that is directly in contact with the product such as a lid, sleeve or protective film.

11.1.18 Waste-to-energy (WtE)

Waste-to-energy is a waste treatment technique designed to recover energy from waste, by which waste is incinerated to produce heat or electricity.

11.1.19 Recycling, upcycling and downcycling

Recycling is when waste materials are converted into new materials for the production of new products. Upcycling is when materials are recycled to produce a higher value or better quality product than the original. Downcycling is a recycling process where the value of the recycled material decreases over time, being used in less valued processes, with lesser quality material and changes in inherent properties when compared to its original use.

Source: Pires A, Martinho G, Rodrigues S, Gomes MI (2019) Sustainable Solid Waste Collection and Management

11.1.20 Take-back scheme

A take-back scheme is when firms retrieve products they manufacture or sell from customers at the products' end of life via third parties or contractors in order to recycle, resell, renovate or dispose of them.

11.2 Terms related to plastics in the environment

11.2.1 Macroplastic

Macroplastics are large plastic waste that are readily visible, with dimensions larger than 5 mm, typically plastic packaging, plastic infrastructure or fishing nets.

Source : Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans : a Global Evaluation of Sources. IUCN

11.2.2 Microplastic

Microplastics are small plastic particulates below 5 mm in size and above 1 μm. Two types of microplastics are contaminating the world's oceans: primary and secondary microplastics.

Source: GESAMP 2019 Guidelines for the monitoring & assessment of plastic litter in the ocean

11.2.3 Primary microplastic

Primary microplastics are plastics directly released into the environment in the form of small particulates. They may be intentionally added to products such as scrubbing agents in toiletries and cosmetics (e.g., shower gels) or they may originate from the abrasion of large plastic objects during manufacturing, use or maintenance such as the erosion of tires when driving or of the abrasion of synthetic textiles during washing.

Source: Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans : a Global Evaluation of Sources. IUCN

11.2.4 Secondary microplastic

Secondary microplastics originate from the degradation of larger plastic items into smaller plastic fragments **once exposed to the marine environment**. This happens through photodegradation and other weathering processes of mismanaged waste such as discarded plastic bags, or from unintentional losses such as fishing nets.

Source: Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans : a Global Evaluation of Sources. IUCN

11.2.5 Nanoplastic

The definition of the term nanoplastics is still under debate, and some authors set the upper size limit at 1000 nm while others 100 nm. Gigault et al. (2018) define nanoplastics as particles with size ranging from 1 to 1000 nm resulting from the degradation of industrial plastic objects that can exhibit colloidal behavior.

Sources:

Lambert, S., Wagner, M., 2016. Characterisation of nanoplastics during the degradation of polystyrene. Chemosphere 145, 265–268. http://dx.doi.org/10.1016/j.chemosphere.2015.11.078

Koelmans A.A., Besseling E., Shim W.J., 2015. Nanoplastics in the Aquatic Environment. Critical Review. In: Bergmann M., Gutow L., Klages M. (eds) Marine Anthropogenic Litter. Springer, Cham. https://doi.org/10.1007/978-3-319-16510-3_12

Gigault J, ter Halle A, Baudrimont M, Pascal PY, Gauffre F, Phi TL, El Hadri H, Grassl B, Reynaud S (2018) Current opinion: What is a nanoplastic? Environmental Pollution 1-5

11.2.6 Leakage, loss and release

The generic term leakage is defined here as the combination of losses and releases.

The loss is the quantity of plastics that leaves a properly managed product or waste management system, as the fraction of materials that is detached from the plastic product during manufacturing, use or transport for microplastics or as mismanaged waste for macroplastics. We define a properly managed waste management system as a system where no leakage is expected to occur such as recycling, incineration or properly managed sanitary landfills. Losses are specific to various sources and activities (e.g., the processes of losing all types of plastics into the environment through abrasion, weathering or unintentional spills during production, transport, use, maintenance or recycling of products containing plastics, and littered plastic packaging).

The releases are the fractions of the loss that are ultimately released into different environmental compartments. The following release pathways are considered throughout this methodology:

- **Releases to waterways and ocean** represent the plastics released to rivers, lakes or directly to oceans.
- **Releases to soils** represent the plastics released to either the soil surface or to deep soil, such as plastics leaching from waste dumps to shallow or deep soils.
- **Releases to terrestrial environment** represent the plastics released to terrestrial environment other than soils, such as plastics deposited and stored in dumpsites, plastics deposited on buildings or trees, or littered plastic packaging.
- **Releases to air** represent the plastic released to air, such as plastic micro- fibers emitted when synthetic textiles are worn.

Source: Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans: a Global Evaluation of Sources. IUCN

11.3 Environmental footprint-related terms

11.3.1 Environmental footprint

A total product environmental footprint is a measure of the pollutant emissions associated with all activities in the product's life cycle. Products are defined as either goods or services. ISO 14044 defines a footprint as "metric(s) used to report life cycle assessment results addressing an area of concern" and defines area of concern as an "aspect of the natural environment, human health or resources of interest to society".

The direct footprint measures specific impacts caused by the firm or any company-owned or company-controlled activities or products. A comprehensive study of all relevant impacts requires the assessment of several impacts, e.g., with a LCA. The indirect footprint measures the impact of other activities related to the company or product but controlled by third parties. A comprehensive environmental assessment is based on a cradle-to-grave approach and considers upstream (suppliers) and downstream (customers) activities of a company."

A Product Environmental Footprint (PEF) is also known as a methodology by the European Commission's Joint Research Center (JRC) which is based on Life Cycle Assessment, which goal is to provide "a common way of measuring environmental performance" for companies within in EU wishing to market their product.

Source : https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/carbon-footprint/

International Organisation for Standardisation (2006). 14044:2006 Environmental management -- Life cycle assessment -- Requirements and guidelines

https://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

11.3.2 Emission factor

An emission factor is defined as the average emission rate of a given pollutant for a given source relative to units of activity.

Source: United Nations Climate Change: https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/definitions

11.3.3 Life cycle

Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

Source: ISO 14040

11.3.4 Life cycle inventory (LCI)

Phase of life cycle assessment involves the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Source: ISO 14040

11.3.5 Life cycle assessment (LCA)

Life cycle assessment (LCA) is an environmental assessment method based on an inventory of potential flow of pollutants entering different compartments of the environment (e.g., air, water, soil) and the assessment of associated impacts of a product system throughout its life cycle.

Source: ISO 14040

11.3.6 Life cycle impact assessment (LCIA)

LCIA is the phase of life cycle assessment that evaluates the magnitude and significance of the potential environmental impacts for a product system throughout the product's life cycle. Impact assessment generally addresses fate, exposure and effect.

Source: ISO 14040

11.3.7 (Elementary) flow

Material or energy entering the system that has been drawn from the environment without prior human transformation, or material or energy leaving the system that is released into the environment without subsequent human transformation.

Source: ISO 14040

11.3.8 Environmental impact

Changes in environmental conditions leading to impacts on the social and economic functions of the environment, such as the provision of adequate conditions for health, resources availability, and biodiversity. Impacts often occur in a sequence: for example, GHG emissions cause global warming (primary effect), which causes an increase in temperature (secondary effect), leading to a rise of sea level (tertiary effect), finally leading to loss of biodiversity.

Source: https://ec.europa.eu/research/evaluations/pdf/archive/other_reports_studies_and_documents/envti0413167enn_002.pdf

11.3.9 Environmental fate

The environmental fate of a chemical describes the proportion of chemical that is transferred to the environment, and the length of time the chemical remains in various environmental media.

Source: Suciu, N., et al., 2012. Environmental Fate Models. In: Bilitewski B., Darbra R., Barceló D. (eds) Global Risk-Based Management of Chemical Additives II. The Handbook of Environmental Chemistry, vol 23. Springer, Berlin, Heidelberg. https://doi.org/10.1007/698_2012_177

11.3.10 Exposure

A "chemical exposure" can be defined as the measurement of both the amount and frequency with which a substance comes into contact with a person or the environment.

Various species in an ecosystem can be exposed to chemicals through different uptake routes, such as inhalation of polluted air or ingestion of polluted water. For example, for human toxicity, exposure can be distinguished between direct intake (e.g., by breathing air and drinking water), indirect intake through bioconcentration processes in animal tissues (e.g., meat, milk and fish) and intake by dermal contact. The fate and exposure of chemicals are generally modelled with multimedia fate and exposure models.

11.3.11 Effect

The effect of a chemical is determined by the sensitivity of a species to that chemical, among other factors, and is often derived from experimental toxicity data. For example, for human toxicity, a chemical effect corresponds to the link between (1) the quantity taken in by a population via a given exposure route, and (2) the adverse effects (or potential risk) generated by the chemical and the severity of disabilities caused by a disease in terms of affected life years.

11.3.12 Circular economy

A circular economy is a global economic model that aims to decouple economic growth and development from the consumption of finite resources.

Source: https://www.ellenmacarthurfoundation.org

A circular economy is a proposed alternative to the traditional linear economy in which products are made, used and then disposed of. The circular economy model aims to keep resources in use for as long as possible to extract their maximum value. This involves the recovery and regeneration of products and materials.

Source: http://www.wrap.org.uk/about-us/about/wrap-and-circular-economy

11.3.13 Circularity

Material circularity is a concept embedded within the circular economy framework. While not an assessment method, circularity is often associated with metrics based on the recycling or reuse rates for different materials.

11.3.14 Value chain

The value chain is the sum of all of the processes involved in cradle-to-grave activities (such as upstream sourcing and production to downstream marketing, after-sales services and product end-of-life) by which a company adds value to a product.

11.3.15 Supply chain

The supply chain of a product includes all of its upstream activities. This includes processes of production and distribution, as well as aspects such as material type and sourcing, and transport between production stages and to markets.

11.3.16 Foreground system

This term refers to processes in the product life cycle for which direct access to specific information is available. For example, the producer's site and other processes operated by a producer or its contractors (e.g.,goods transport, head-office services, etc.) belong to the foreground processes.

Source: Product Environmental Footprint Pilot Guidance. Guidance for the implementation of the EU Product Environmental Footprint (PEF) during the Environmental Footprint (EF) pilot phase, 2016.

11.3.17 Background system

This term refers to processes in the product life cycle for which no direct access to specific information is available. The background process is outside the direct influence of the producer or service operator.

Source: Product Environmental Footprint Pilot Guidance. Guidance for the implementation of the EU Product Environmental Footprint (PEF) during the Environmental Footprint (EF) pilot phase, 2016.

11.4 Working group specific definitions

11.4.1 Tire and road wear particles

Tire wear particles are generated by friction between a tire and the road; this friction ensures a sufficient grip on the road and safety. Particles are not simply rubber flecks from the tire, but an agglomeration of material from the tire and the road. They are therefore identified as Tire and Road Wear Particles (TRWP).

Source: http://www.etrma.org/uploads/Modules/Documentsmanager/20180320-etrma-trwp-plastics-strategy.pdf

11.4.2 Littering

Littering is the improper disposal of small, one-off items, such as throwing a cigarette butt, dropping a snack packet or tossing a plastic drink cup. Most of the time these items end up on the road or sidewalk. They may or may not be removed by municipal street cleaning.

Source : http://speedy-waste.co.uk/news/whats-the-difference-between-littering-and-fly-tipping

11.4.3 Fly tipping

Fly tipping is the deliberate disposal of larger quantities of litter in the environment without any specific location. This could be anything from a single bag of rubbish to a large sofa to a broken refrigerator, accumulating on the roadside or in remote places.

Source : http://speedy-waste.co.uk/news/whats-the-difference-between-littering-and-fly-tipping

11.4.4 Dumping

Dumping is the deliberate disposal of larger quantities of litter in an unauthorized area. Dumping can be the result of the formal or informal collection sector. Discarded items could range from a single bag of rubbish to a large sofa or broken refrigerator.

Source : http://speedy-waste.co.uk/news/whats-the-difference-between-littering-and-fly-tipping

11.4.5 Sanitary landfills

Landfilling is the deliberate disposal of larger quantities of litter in a particular area that is controlled (where waste is covered on a daily basis, and the bottom of the landfill is designed to avoid spills). Landfilling is typically part of a formal collection sector.

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Appendices

13

Appendix A – Literature review to define the plastic degradation rate

It is important to note more standardized metrics are needed to differentiate degradation rates in natural compartments in order to better characterize the biodegradation rate of plastics. Standard methods have been published for some natural compartments but not all, and for now they are still used in only a minority of studies. The use of these standardized metrics will enable the comparison and ranking of plastic materials in terms of biodegradability, information relevant for environmental fate estimation.

The current techniques for assessing the biodegradation of polymers, listed in the review from Raddadi and Fava (2019), are the following:

- Standard methods to measure gas production or consumption (ASTM D5988, ISO 17556, ASTM D6691, ISO 14851). These evaluate the biodegradation of plastics/polymers under aerobic or anaerobic conditions by measuring the gas released or taken in. These methods are the most widely used and the most efficient to assess complete biodegradation. Limitation: Fossil-based plastics show a very small amount of gas released, so this method exhibits very low sensitivity. Moreover, the gas production can potentially be associated with the degradations of other compounds present in the matrix in which the test is performed.
- Gravimetric determination of weight loss. This method is very widely used as well. Limitation: the weight loss can be due to the release of additives or chemical hydrolysis and fragmentation/disintegration of plastics, and since the weight is usually very small there is a high chance of inaccuracy.
- Thermogravimetric analysis: measures thermal stability. Limitation: the additive components contribute to the final thermal stability of plastic.
- Differential scanning calorimetric analysis: assesses different thermal properties of the materials.
- Gel permeation chromatography: indicates average molecular weight and molecular weight distribution. Limitation: it is not a highly sensitive technique since it is performed on the bulk and not the surface.

- Fourier transform infrared spectroscopy. Used to reveal chemical modifications of the polymer structure and monitor chemical changes in polymeric film. Enables detection of the formation of functional groups as a result of microbial attack. Limitation: it is not good for plastics with large amounts of additives.
- Microscopy observation of the surface. Observation of cracks and holes, or the microbial colonization formation of biofilm. Limitation: Colonization of a polymer surface is not proof of biodegradability since the polymer surface could be used by the microbe as a support for biofilm formation.
- Radiolabeling. Labelling the carbon in a polymer to be used as substrate for microbial growth with carbon isotope 14C. The mineralization is then confirmed by measuring the radioactive gas produced (14CO2, 14CH4). Highly precise technique. Limitation: the challenges and cost of preparing the radioactive polymer as well as managing and disposing of radiolabeled samples.
- A last method not mentioned by (Raddadi and Fava 2019) but used in a few studies is viscometric analysis. This is a measurement of the intrinsic viscosity of a polymer and leads to the calculation of its molecular weight and chain scission. Limitation: it does not measure total biodegradation, but only the rate of depolymerization.

Only results assessing gas production and consumption with a standardized method were considered to define the degradation time in these guidelines, since they are the only ones that give a reliable and comparable quantitative value of mineralization over time.

The exhaustive list of literature reviewed on degradation time of different polymers and plastics is provided in the document:
PLP_Biodegradation_rate_literature_review_Quantis_EA.xls.

Appendix B – Literature review to define wastewater treatment plant removal efficiencies

Table 13-1 shows the key results from the literature review on microplastic removal efficiency in wastewater treatment plants and table 13-1 presents the literature review sources.

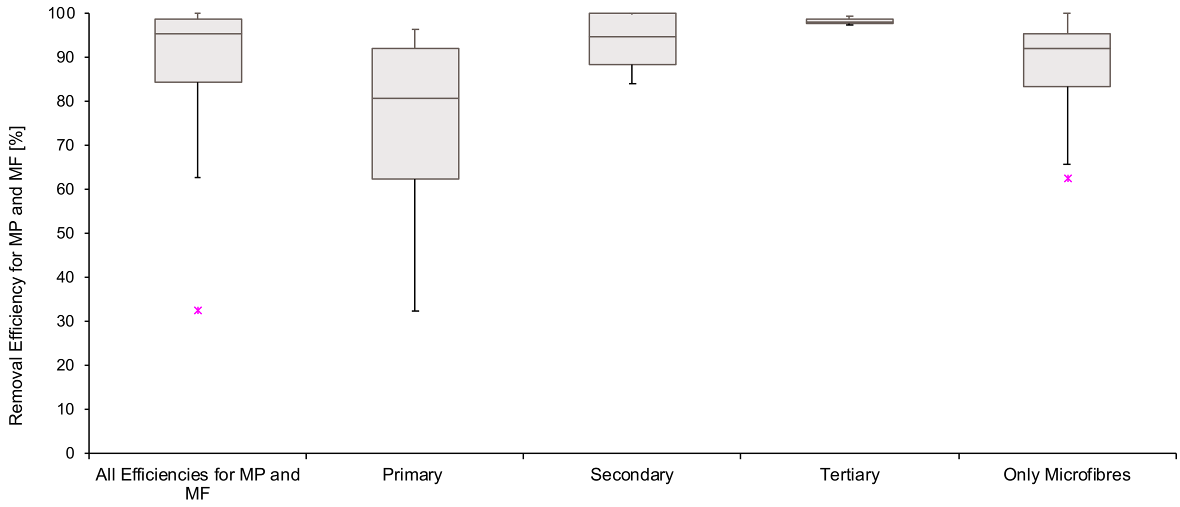

Figure 13.1: Removal efficiency for different levels of waste water treatment (primary, secondary and tertiary)

Table 13-1: Literature sources for wastewater treatment plant removal efficiencies

Reference	Treatment	Microplastics OR Microfibers	All Efficiencies for MP and MF [%]
(Magnusson and Norén 2014)	Secondary	MP	99.9
(Magnusson and Norén 2014)	Secondary	MF	100.0
(Talvitie and Heinonen 2014)	Primary	MP	96.3
(Talvitie et al. 2015)	Primary	MF	92.1
(Talvitie et al. 2015)	Secondary	MF	92.3
(Talvitie et al. 2015)	Tertiary	MF	97.3
(Talvitie et al. 2015)	Primary	MP	32.4
(Talvitie et al. 2015)	Secondary	MP	84.0
(Talvitie et al. 2015)	Tertiary	MP	98.0
(Dris et al. 2015)	Primary	MF	80.8
(Dris et al. 2015)	Secondary	MF	94.6
(Dris et al. 2015)	Primary	MF	62.5
(Dris et al. 2015)	Secondary	MF	84.4
(Murphy et al. 2016)	Secondary	MP	98.4
(Carr et al. 2016)	Secondary	MP	99.9
(Simon et al. 2018)	Tertiary	MP	99.3
Median value	Primary	MP and MF	80.8
Median value	Secondary	MP and MF	94.6
Median value	Tertiary	MP and MF	98.0

Siegfried et al. (2017) considered a removal efficiency of 95% for wastewater treatment plants with at least a primary treatment, which corresponds to the values mentioned by reviewed publications. However, they do not provide a treatment efficiency per level of treatment; this is why the reference was not added to this literature review.

Appendix C – Literature review to define synthetic microfiber loss rates during a wash

Figure 13-2 and table 13-2 show the key results from the literature review on synthetic microfiber loss rates during a wash and table 13-3 presents the literature review sources.

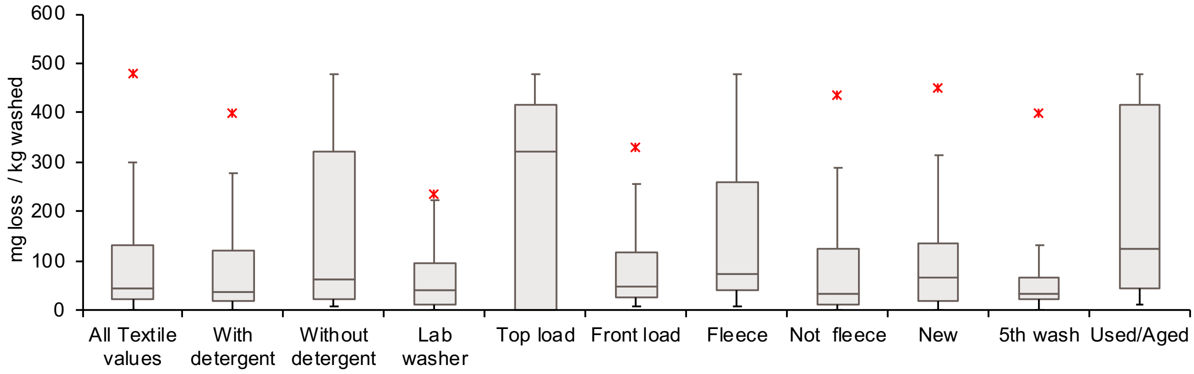

Figure 13-2: Loss rate reported in literature for textiles grouped according different criteria (wash with/without detergent, type of washing machine, fleece versus non-fleece, new versus used garments)

Table 13-2: Literature review key results for loss rates per textile groups [mg/kg washed]

	All textile values	With detergent	Without detergent	Lab washer	Top load	Front load	Fleece	Not fleece	New	5th Wash	Used/ aged
Min	0,1	0,1	8,0	0,1	0,1	8,0	8,0	0,1	0,1	0,1	10,8
Q_1	**24**	**19**	**23**	**12**	**0,3**	**25**	**42**	**14**	**20**	**25**	**44**
Median	**46**	**39**	**64**	**40**	**320**	**50**	**75**	**35**	**67**	**33**	**120**
Q_3	**1230**	**120**	**320**	**96**	**420**	**120**	**260**	**120**	**140**	**70**	**420**
Max	480	400	480	240	480	330	480	430	450	400	480
IQR	110	103	300	84	420	93	220	110	120	44	370
Upper Outliers	11	3,0	-	2,0	-	1,0	-	5,0	4,0	4,0	-
Lower Outliers	-	-	-	-	-	-	-	-	-	-	-
Average	110	80	160	60	240	81	150	89	120	65	200
Number of values	80	49	31	19	16	23	28	52	40	31	12

Table 13-3: Literature sources for loss rates per textile groups

Reference	Washing parameters	Type of product	Loss rate in mg lost / kg washed
De Falco, 2018	No detergent	Plain weave polyester USED (5th wash)	12.0
De Falco, 2018	No detergent	Double knit jersey polyester USED (5th wash)	13.0
De Falco, 2018	No detergent	Plain weave polypropylene USED (5th wash)	17.0
De Falco, 2018	With liquid detergent	Plain weave polyester USED (5th wash)	92.0
De Falco, 2018	With liquid detergent	Double knit jersey polyester USED (5th wash)	235.0
De Falco, 2018	With liquid detergent	Plain weave polypropylene USED (5th wash)	57.0
De Falco, 2018	With Powder detergent	Plain weave polyester USED (5th wash)	255.0
De Falco, 2018	With Powder detergent	Double knit jersey polyester USED (5th wash)	399.0
De Falco, 2018	With Powder detergent	Plain weave polypropylene USED (5th wash)	146.0
Hernandez, 2017	No detergent	Jersey and interlock (NEW and USED, after prewash)	25.0
Hernandez, 2017	With liquid detergent	Jersey and interlock (NEW and USED, after prewash)	100.0
Hernandez, 2017	With Powder detergent	Jersey and interlock (NEW and USED, after prewash)	100.0
Hartline, 2016	No detergent	Technical non fleece jacket NEW A	180.0
Hartline, 2016	No detergent	Synthetic fleece pullover NEW B 85%recycl. Polyester + 15% polye	161.6

Hartline, 2016	No detergent	Synthetic fleece pullover AGED B 85%recycl. Polye + 15% polye	450.5
Hartline, 2016	No detergent	Synthetic sweater fleece jacket NEW D 100% Polyester	210.0
Hartline, 2016	No detergent	Synthetic sweater fleece jacket AGED D 100% Polyester	400.3
Hartline, 2016	No detergent	Synthetic sweater fleece jacket NEW 100% Polyester cheap brand E	780.0
Hartline, 2016	No detergent	Synthetic sweater fleece jacket AGED 100% Polyester cheap brand E	706.7
Pirc, 2016	No detergent	100% fleece blanket/ ave of 8th-10th wash --> USED	10.8
Pirc, 2016	No detergent	100% fleece blanket / 2nd wash--> NEW	55.0
Pirc, 2016	No detergent	100% fleece blanket / 1st wash--> NEW	160.6
Pirc, 2016	With liquid detergent	100% fleece textile/ ave of 8th-10th wash --> USED	14.0
Pirc, 2016	With liquid detergent	100% fleece textile/ 2nd wash --> NEW	34.8
Pirc, 2016	With liquid detergent	100% fleece blanket / 1st wash--> NEW	97.6
CNR, 2018	With liquid detergent	T-shirt, 100% polyester NEW	125.0
CNR, 2018	With liquid detergent	T-shirt, 100% polyester (65%recycl.p.) NEW	48.6
CNR, 2018	With liquid detergent	T-shirt, 100% polyester NEW	124.1
CNR, 2018	With liquid detergent	T-shirt, 100% polyester (front only) NEW	307.6
Belzagui, 2019	With liquid detergent	100% polyester – woven fluffy fabric (5th wash, front load)	33.1
Belzagui, 2019	With liquid detergent	100% polyester – woven fluffy fabric (5th wash, front load)	34.6
Belzagui, 2019	With liquid detergent	100% polyester – woven fluffy fabric (5th wash, front load)	31.1
Belzagui, 2019	With liquid detergent	100% polyester – knitted fluffy fabric (5th wash, front load)	55.6
Belzagui, 2019	With liquid detergent	100% polyester – woven fluffy fabric (5th wash, front load)	39.8
Belzagui, 2019	With liquid detergent	100% polyester – knitted shirt (5th wash, front load)	25.7
Belzagui, 2019	With liquid detergent	100% polyester – woven nightgown (5th wash, front load)	24.5
Belzagui, 2019	With liquid detergent	80% polyester 20% elasthane – knitted shirt (5th wash, front load)	38.8
Belzagui, 2019	With liquid detergent	80% polyester 20% elasthane – knitted gym pants (5th wash, front load)	30.1
Belzagui, 2019	With liquid detergent	80% polyester 20% elasthane – knitted jacket (5th wash, front load)	29.8
Belzagui, 2019	With liquid detergent	70% acrylic 30% polyamide – knitted woolen cap (5th wash, front load)	79.7
Zambrano, 2019	With liquid detergent	100% polyester – weft knitted interlock fabric NEW (lab washer)	12
Zambrano, 2019	With liquid detergent	100% polyester – weft knitted interlock fabric (3rd wash, lab washer)	7
Zambrano, 2019	Without detergent	100% polyester – weft knitted interlock fabric NEW (44°C, accelerated laundering)	46
Zambrano, 2019	With liquid detergent	100% polyester – weft knitted interlock fabric NEW (44°C, accelerated laundering)	230
Zambrano, 2019	Without detergent	100% polyester – weft knitted interlock fabric NEW (25°C, accelerated laundering)	40

Zambrano, 2019	With liquid detergent	100% polyester – weft knitted interlock fabric NEW (25°C, accelerated laundering)	130
Napper and Thompson, 2016	With detergent	100% polyester, jumper, NEW (front load)	0.17
Napper and Thompson, 2016	With detergent	100% acrylic, jumper, NEW (front load)	0.47
Napper and Thompson, 2016	With detergent	65% polyester, 35% cotton, jumper, NEW (front load)	0.075
Napper and Thompson, 2016	With detergent	100% polyester, jumper (5th wash, front load)	0.17
Napper and Thompson, 2016	With detergent	100% acrylic, jumper (5th wash, front load)	0.29
Napper and Thompson, 2016	With detergent	65% polyester, 35% cotton, jumper (5th wash, front load)	0.067
Carney Almroth, 2018	With liquid detergent	100% polyester (lab washer)	0.32
Carney Almroth, 2018	With liquid detergent	100% nylon (lab washer)	0.071
Carney Almroth, 2018	With liquid detergent	100% acrylic (lab washer)	0.14
Carney Almroth, 2018	With liquid detergent	100% polyester fleece (lab washer)	42
Carney Almroth, 2018	With liquid detergent	100% polyester microfleece (lab washer)	43
Folkö, 2015	Without detergent	100% polyester fleece shirt NEW (front load)	115
Folkö, 2015	Without detergent	57% polyamide 43% polyester – sport sweater NEW (front load)	25
Sillanpää Sainio, 2017	With liquid detergent	Fleece NEW (front load)	120
Sillanpää Sainio, 2017	With liquid detergent	Fleece NEW (front load)	130
Sillanpää Sainio, 2017	With liquid detergent	Softshell NEW (front load)	230
Sillanpää Sainio, 2017	With liquid detergent	Technical sport shirt NEW (front load)	330
Sillanpää Sainio, 2017	With liquid detergent	Fleece (5th wash, front load)	30
Sillanpää Sainio, 2017	With liquid detergent	Fleece (5th wash, front load)	50
Sillanpää Sainio, 2017	With liquid detergent	Softshell (5th wash, front load)	25
Sillanpää Sainio, 2017	With liquid detergent	Technical sport shirt (5th wash, front load)	35

Appendix D – Literature review to define the tire tread loss for different types of vehicles

Figure 13-3 shows the 5th percentile, 1st quartile, median, 3rd quartile and 95th percentile values of the tread loss per type of vehicle that are also shown in Table 13-4. Table 13-5 shows the details of the literature sources used for this analysis.

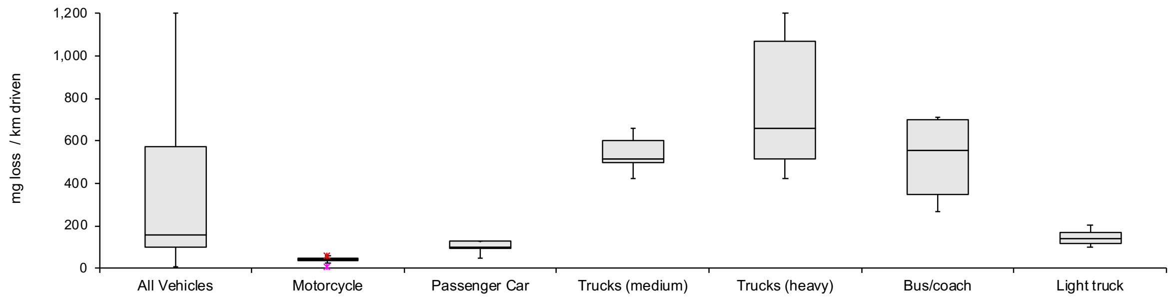

Figure 13-3: Loss rate reported in literature for tread loss of different types of vehicles

Table 13-4: Loss rate reported in literature for tread loss of different types of vehicles

Labels	All Vehicles	Motorcycle	Passenger Car	Trucks (medium)	Trucks (heavy)	Bus/ coach[28]	Light truck
Min	7	7	50	423	423	267	102
Q_1	**100**	**39**	**93**	**495**	**517**	**348**	**119**
Median	**159**	**45**	**102**	**517**	**658**	**558**	**142**
Q_3	**573**	**47**	**129**	**600**	**1'068**	**700**	**170**
Max	1'200	60	132	658	1'200	712	204
IQR	473	8	37	105	551	352	51

[28] The values reported in Magnusson et al. 2016, UNECE 2013 and Hillenbrand et al. 2005 are actually not relevant for buses, since they were estimated based on lorry loss rates, and were therefore excluded from the scope to calculate average values for buses. As a consequence, the loss rates for buses were calculated only based on values from the Netherlands statistics, the only study that provides specific loss rates for buses. The value of "highway" was used for coach, and the value of "urban road" was used for city bus.

Table 13-5: Literature sources for tread loss rates per type of vehicles

Reference	Type of vehicle	Geographical context	Tread loss in mg / (vhc.km)
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	motorcycle/ urban road	The Netherlands	60
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	motorcycle / rural road	The Netherlands	39
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	motorcycle/ highway road	The Netherlands	47
Hillenbrand et al., 2005	motorcycle	Germany	45
Aatmeeyata, Kaul, & Sharma, 2009	motorcycle / 2 & 3 wheelers	China/India/Brazil/USA	7
Kole, Löhr, & Ragas, 2015	Passenger Car	The Netherlands	100
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Passenger Car / urban road	The Netherlands	132
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Passenger Car / rural road	The Netherlands	85
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Passenger Car / highway road	The Netherlands	104
(Magnusson et al. 2016)	Passenger Car	Sweden	50
Luhana et al., 2004	Passenger Car	Norway	100
UNECE, 2013	Passenger Car	Norway/Denmark	132
Hillenbrand et al., 2005	Passenger Car	Germany	90
Milani et al., 2004	Passenger Car	Italy	120
UNECE, 2013	Passenger Car	China/India/Brazil/USA	132
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	light commercial/(Van/special vehicle light)/ urban road	The Netherlands	159
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	light commercial/(Van/special vehicle light)	The Netherlands	102
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	light commercial/(Van/special vehicle light)	The Netherlands	125

UNECE, 2013	light commercial/ light duty lorries	Denmark/China/India/Brazil/USA	204
Kole, Löhr, & Ragas, 2015	Lorry	The Netherlands	600
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Articulated lorry/heavy truck	The Netherlands	495
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (TRUCK/urban road)	The Netherlands	658
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (TRUCK/rural road)	The Netherlands	423
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (TRUCK/highway road)	The Netherlands	517
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (BUS/urban road)	The Netherlands	415
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (BUS/rural road)	The Netherlands	267
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (BUS/highway road)	The Netherlands	326
(Magnusson et al. 2016)	Trucks/Lorry/Bus	Sweden	700[28]
UNECE, 2013	Trucks/Lorry/Bus	Norway/Denmark	712[28]
Hillenbrand et al., 2005	Trucks/Lorry/Bus	Germany	700[28]
Hillenbrand et al., 2005	Articulated Lorry/heavy truck	Germany	1200
UNECE, 2013	Articulated Lorry/heavy truck	China/India/Brazil/USA	1068
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (LORRY/urban road)	The Netherlands	658
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (LORRY/rural road)	The Netherlands	423
Verschoor, De Poorter, Dröge, Kuenen, & De Valk, 2016	Trucks/Lorry/Bus (LORRY/highway road)	The Netherlands	517

Appendix E – Literature review of road marking and brake wear particles

On top of TRWP, microplastics released through transportation also include road marking and brake wear particle emissions. However, after a literature review it was decided to exclude them from the current version of these guidelines because i) the amount of microplastics released through these two means is much smaller than that of TRWP, and ii) there is a lack of reliable data on the topic.

Typical road marking paints are either thermoplastic or water-based. The plastic polymer content for thermoplastic road marking was estimated in Sundt et al. (2014) to be 1-5%, and for polymer paints as high as 15-40% in Lassen et al. (2015). In comparison, tire wear is estimated to consist of 35% to 50% microplastics as presented in the guidelines. The ratio of microplastic emissions from road marking and from tire tread found in the literature is shown in the table below.

Table 13-5: Emissions of microplastics from road marking

Polymer fraction of **road marking** emitted [t/year]	Polymer fraction of **tire tread** emitted [t/year]	Ratio of **road marking polymer fraction emissions / tire tread polymer fraction emissions** [-]	Reference
86 – 176	4250	2.0 – 4.1	Vogelsang et al. (2019) Area of study: Norway
10 – 180	500 – 1700	0.6 – 36	Lassen et al. (2015) Area of Study: Denmark
504	13’000	3.9	Magnusson et al. (2016) Area of study: Sweden
320	4500	7.1	Sundt et al. (2014) Area of study: Norway

Based on these data points we surmise that the amount of microplastics released from road marking is relatively small compared to that of tire tread, with an average ratio around 5%. Moreover, it should be noted that studded snow tires used during the winter in Nordic countries have a highly abrasive effect on road marking (Lassen et al. (2015)), as do snowplows. Therefore the amount of road marking abrasion depends on climate, so this data cannot be transposed easily to any country.

Regarding brake wear particles, even less information is available. There is no clear estimate of the percentage of microplastics in brake lining, but we know from Grigoratos and Martini (2014) that Kevlar fibers can be found, and act as binders from phenol-formaldehyde resins. As a rough estimate, we assume the polymer content of brake lining to be 5-15%. Most of the studies that provide values for break wear and tire tread emissions only indicate PM10 air emissions, as indicated in the table below. Grigoratos and Martini (2014) estimated that about half of brake wear emissions become airborne, compared to only a tenth of tire wear emissions (in the current version of the guidelines, the proportion of PM10 air emissions is 2% of total TRWP emissions). The ratio of brake wear to tire tread emissions in the table takes this into account to estimate the ratio of the total amount rather than just the airborne part.

Table 13-6: Emissions of particles from brake wear

PM10 emissions from **brake wear** [mg/km]	PM10 emissions from **tire tread** [mg/km]	Ratio of **brake wear emissions / tire tread emissions** [-]	Reference
7.9	5.0	32	USEPA (1995) taken from Grigoratos and Martini 2014
1.8 – 4.9	6.5	6 – 15	Lükeville et al. (2001) taken from Grigoratos and Martini 2014
8.8	7.4	24	Luhana et al. (2004) taken from Grigoratos and Martini 2014
7	7	20	NAEI (2012) taken from Grigoratos and Martini 2014

Kole et al. (2017) in Germany estimate the amount of brake wear to be about 11% of that of tire wear, which is lower than many of the results in the table above.

There is no precise information on the amount of microplastics in brake wear nor the amount of microplastics that brake wear emits so we cannot compare it to the amount of microplastics released from tire tread. However, given the high ratio of brake wear to tire tread obtained from the literature, it would be worthwhile to research this topic further.

Appendix F – Actions to close the plastic leak tap

This section reflects the outcomes of the November 26, 2019 workshop during which actions to reduce plastic leakage in three sectors were discussed. Presented in this section are preliminary assessments and first steps towards a plastic leakage strategy. Actions are classified according to categories outlined in Figure 13.2.

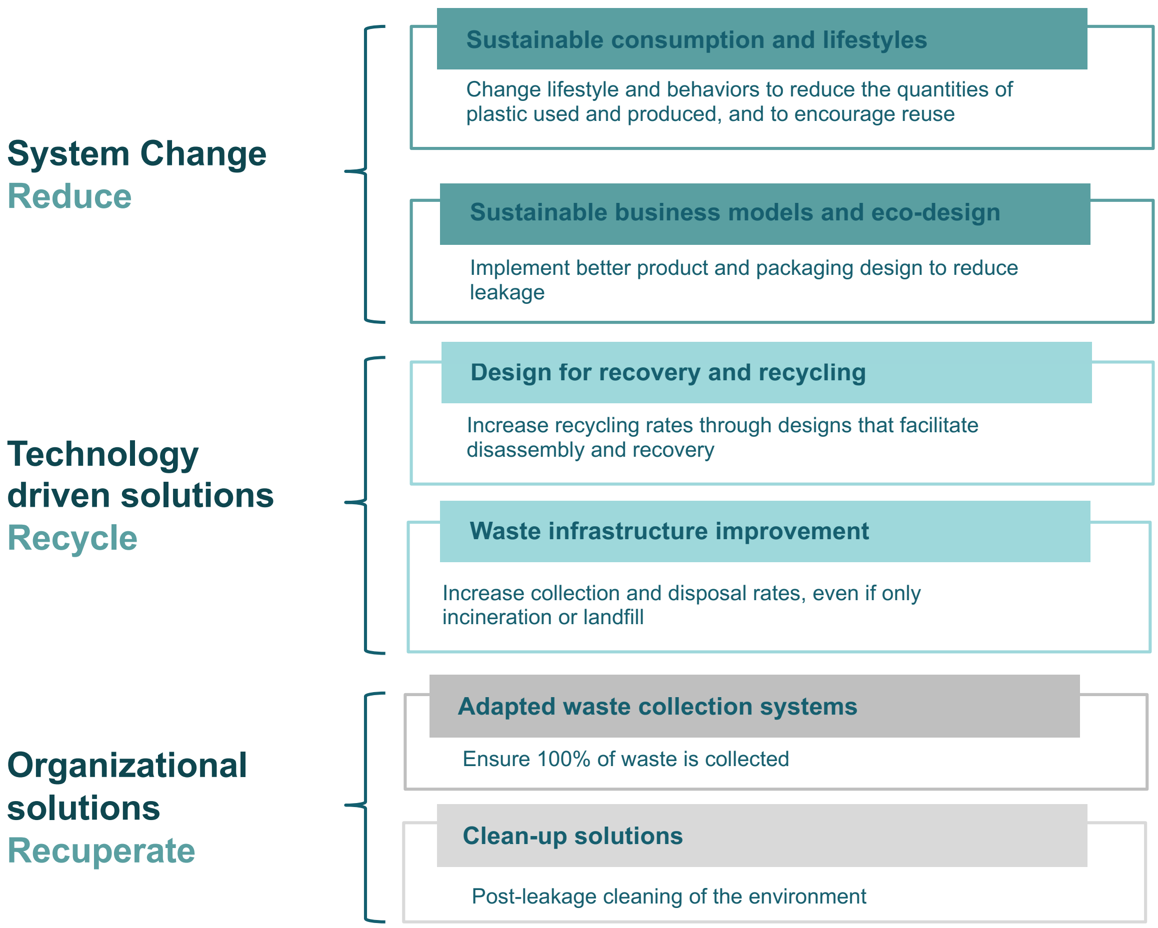

Figure 13.2: Plastic leakage reduction actions classified by UNEP and IUCN (2020)

Types of actions that could be implemented based on a plastic leakage assessment were identified for three sectors:

- Food (based on the Arla Foods case study)
- Textile (based on the Sympatex Technologies case study)
- Cosmetics (fictive case study on liquid soap bottle)

Participants in each group discussed different types of plastic leakage reduction actions and selected the five most relevant in terms of ease of implementation and potential reduction. The five actions were positioned on a graph according to these factors, with cost information represented by the circle size. The principal outcomes are shown below in Figure 13.3.

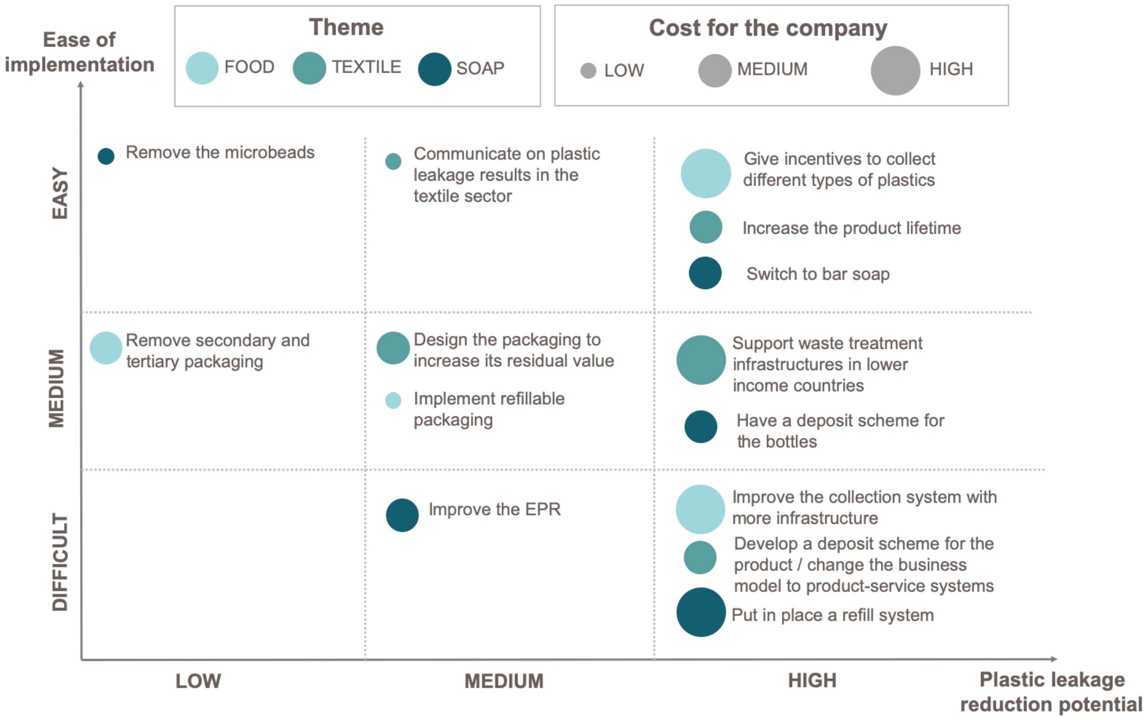

Figure 13.3: Plastic leakage reduction actions classified by potential, ease of implementation and cost

The key outcomes of the discussions are summarized as follows:

- In general, when the impact of a product is dominated by production and/or the end-of life, the most efficient action is to increase the usable lifetime of the product. This is valid for both packaging (single use plastic should be replaced by more durable/reusable alternatives) and textiles (where longer lifetime enables a product to deliver more utility/function while minimizing both carbon impacts and plastic leakage).
- The actions with the greatest abatement potential are related to an improvement in waste management by increasing recycling rates and reducing mismanaged waste; this is not an easy task and can be put in place only collaborating with other stakeholders like EPR and other companies. Another action with significant abatement potential is to create deposit schemes or refill systems, and may be less complicated to implement.
- Actions that are easy or medium-easy to implement are removing all unnecessary packaging and plastics.
- In terms of cost, actions with the greatest reduction potential were also the most expensive. Actions involving packaging changes were often deemed not too expensive, with a medium ease of implementation and medium reduction potential.

Data repository

14

The attached document PLP_Sectorial_Guidances_Generic_data summarizes all suggested secondary data to support a plastic leakage assessment through different calculation routes. These should be used as default values if no primary data or specific secondary data are available.

Case studies

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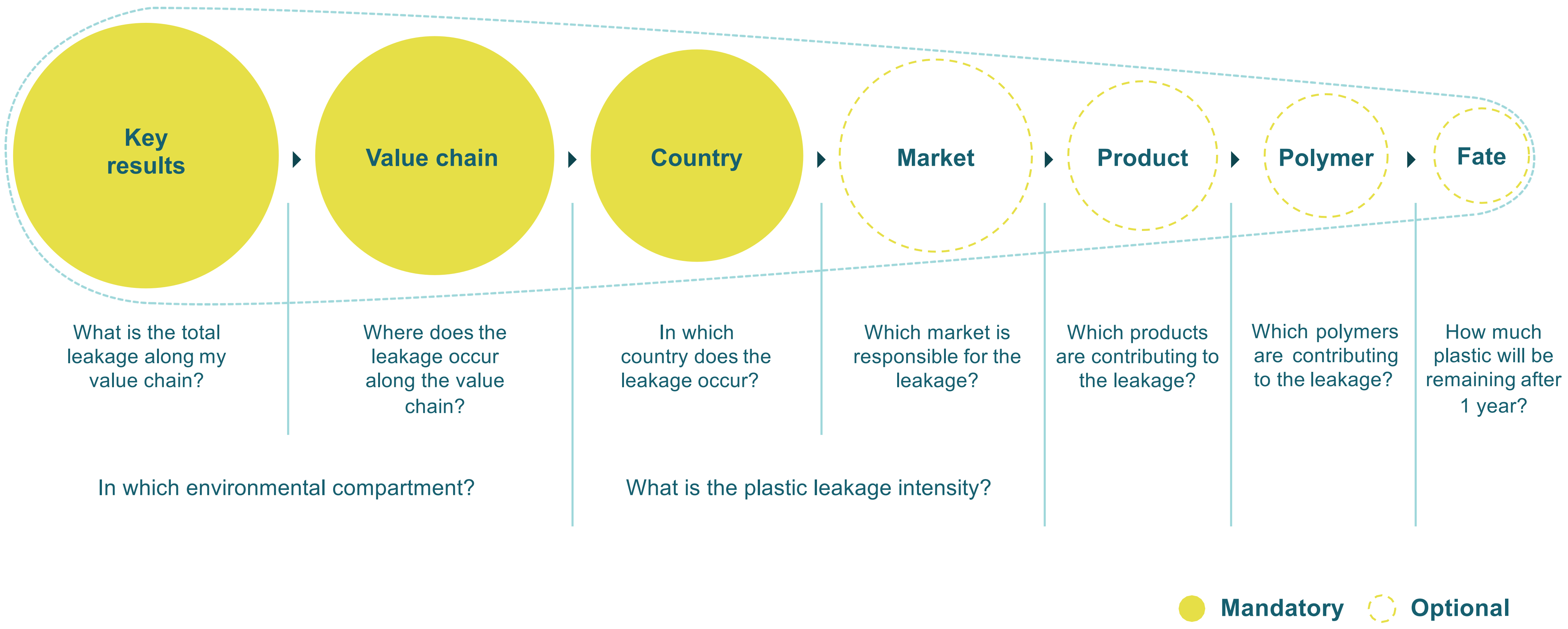
The following case studies illustrate some key outputs from a plastic leakage assessment both at the product and corporate levels.

ARLA case study

What perspective on plastic leakage?

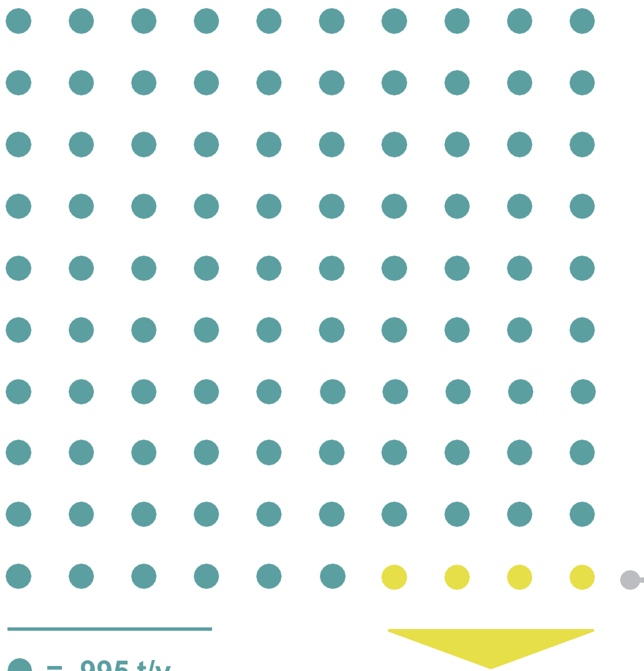


Key results

What is the total leakage along my value chain?

99'466 t/y
Macroplastic used

1'355 million tkm
Road transport



= 995 t/y

4% **Plastic leakage intensity**

882 t/y

Leakage into ocean

99% Macro

2'877 t/y

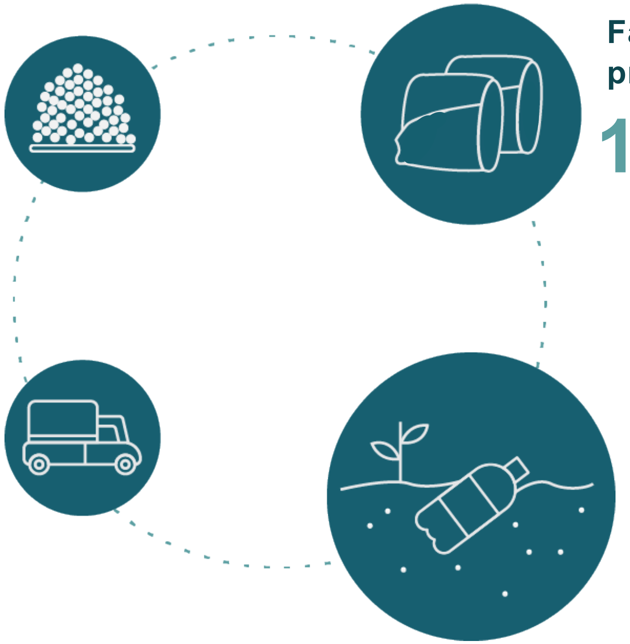
Leakage into other environmental compartments (soil, river, sediments and air)

98% Macro

Value chain

Where does the leakage occur along the value chain?

In which environmental compartment?



Packaging production
9 t/y

Farms and production site
124 t/y

5%	Ocean
95%	Other terrestrial environment

Transport
31 t/y

2-3%	Ocean
2-4%	Other terrestrial environment
76-79%	Soil
16-18%	Freshwater

Product end-of-life
3’595 t/y

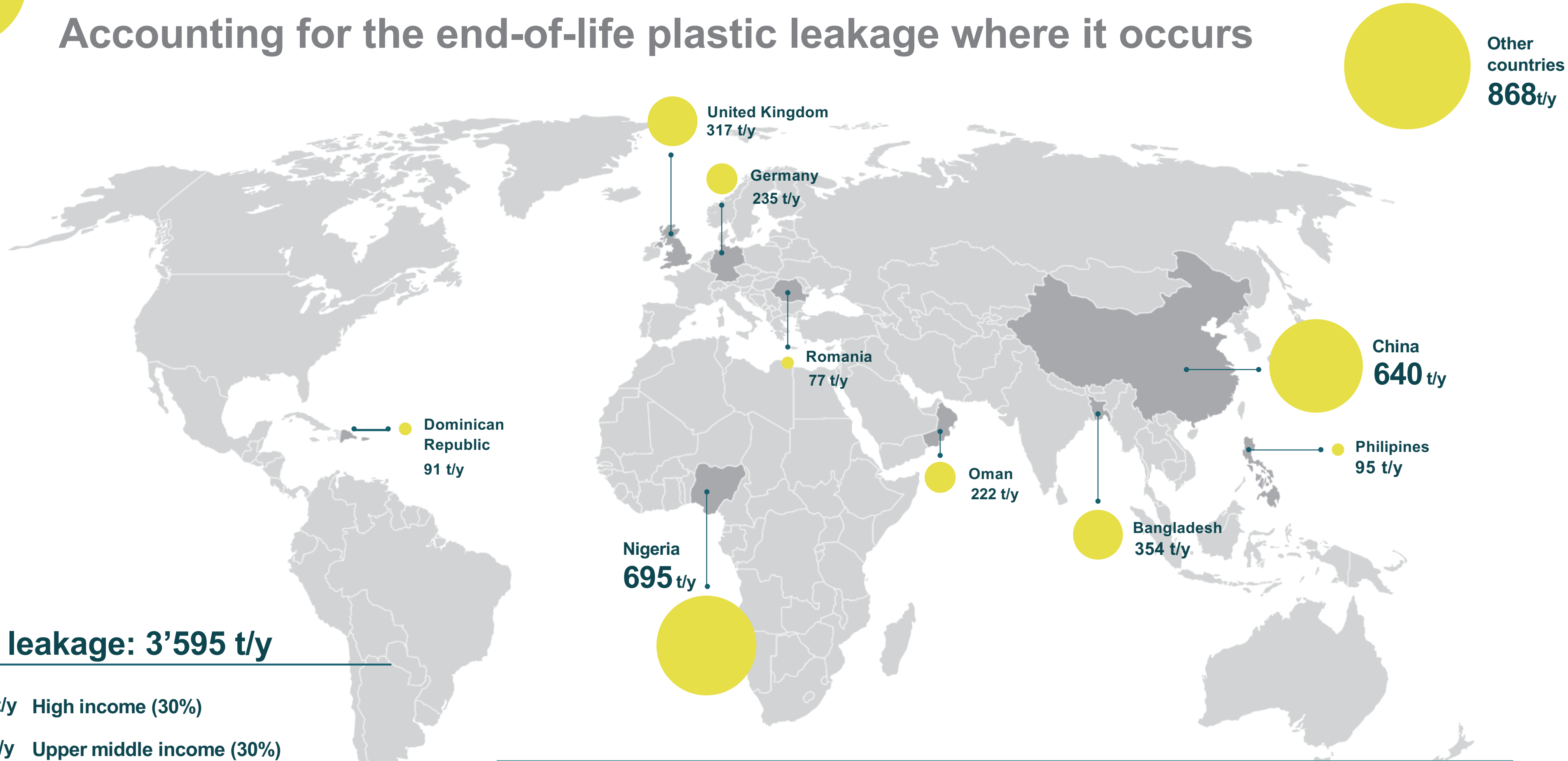
24%	Ocean
76%	Other terrestrial environment

The plastic leakage occurs mainly when the plastic packaging is disposed at its end-of-life

Country

In which country does the leakage occur?

Accounting for the end-of-life plastic leakage where it occurs



Total leakage: 3’595 t/y

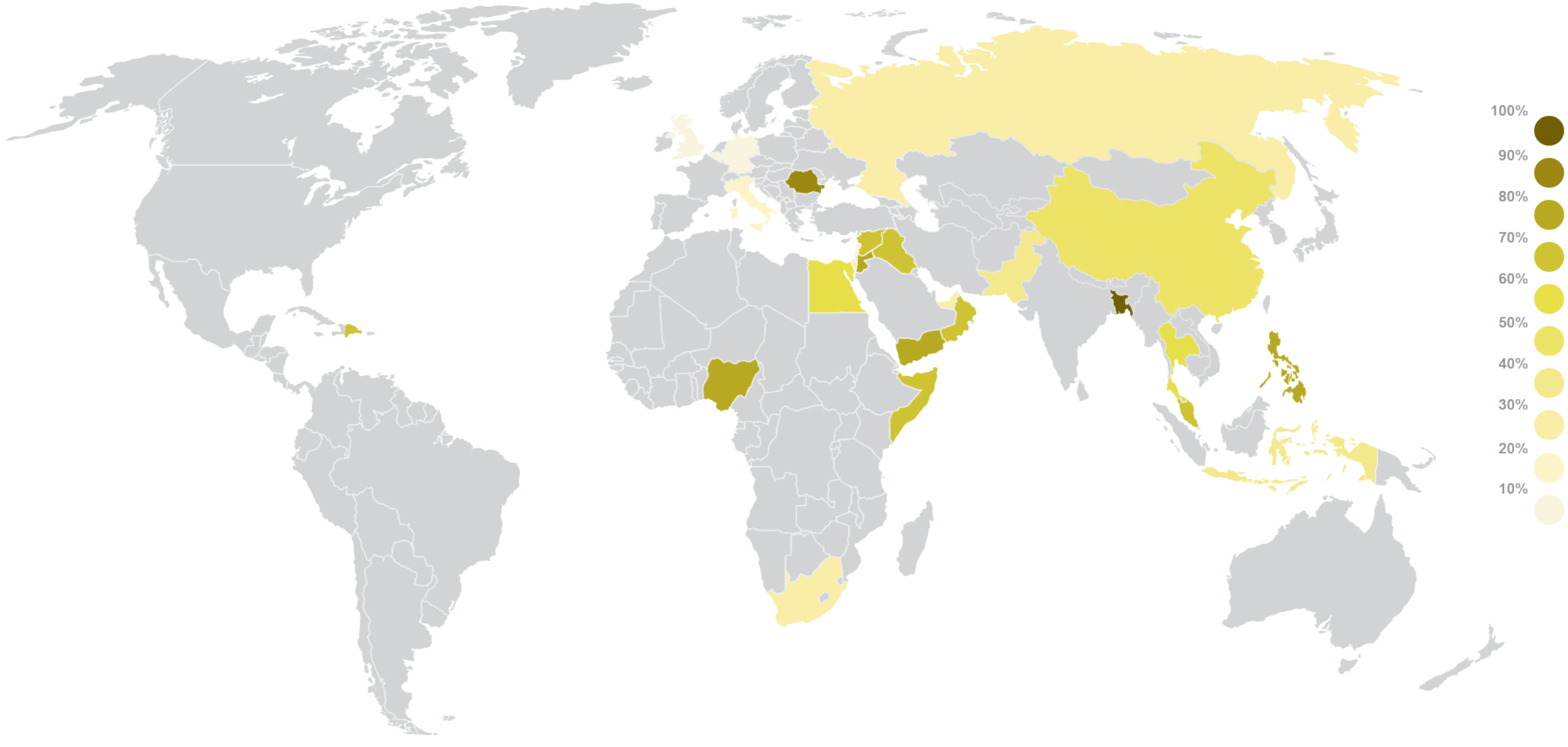
1’086 t/y	High income (30%)
1’074 t/y	Upper middle income (30%)
1’336 t/y	Lower middle income (37%)
99 t/y	Lower income (3%)

The end-of-life leakage occurs mainly in Nigeria, China and Bangladesh

Country

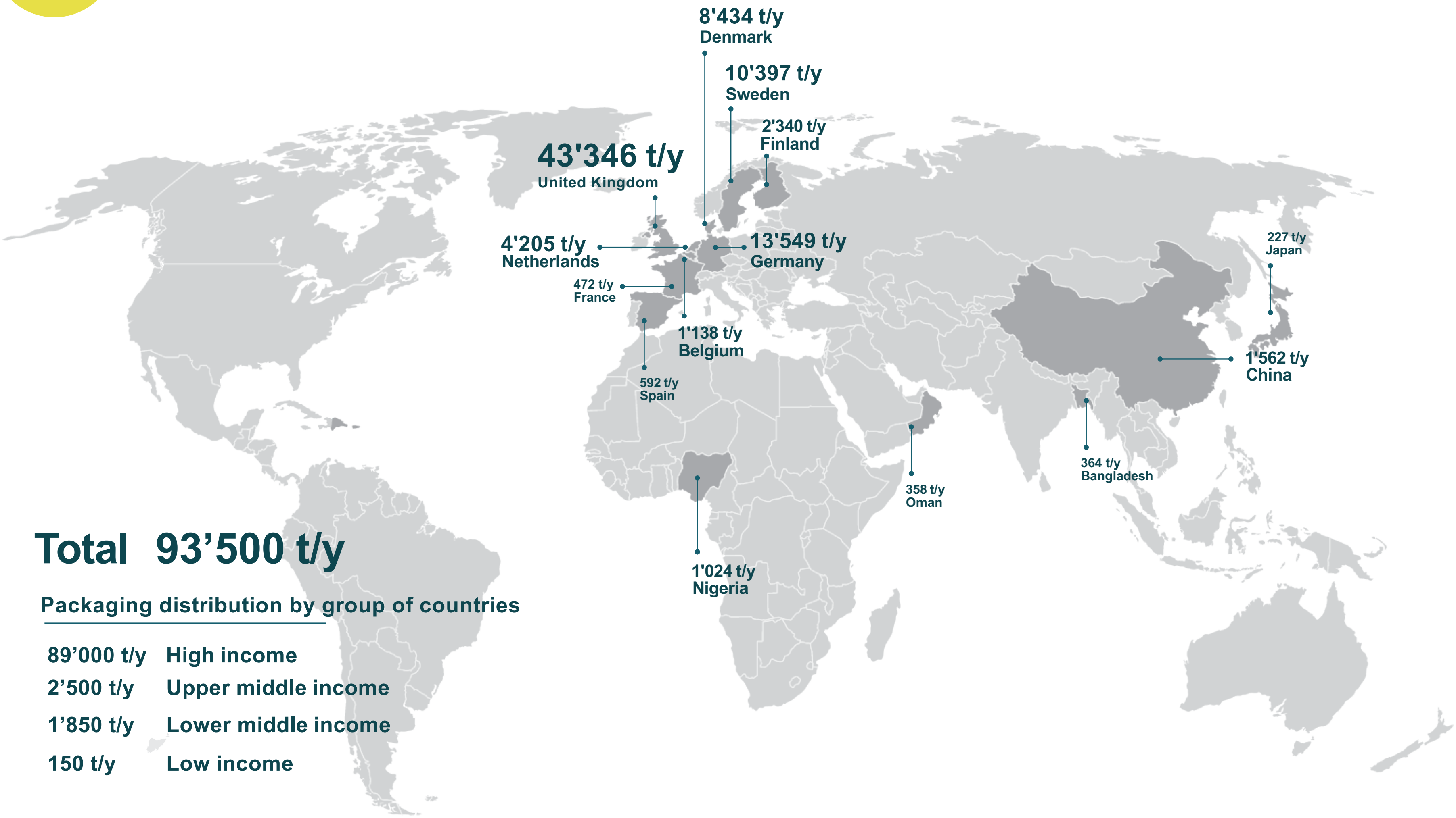
What is the plastic leakage intensity?

What is the % leakage per t product distributed in each country?



Country

Where are the packagings distributed?



Total 93’500 t/y

Packaging distribution by group of countries

89’000 t/y	High income
2’500 t/y	Upper middle income
1’850 t/y	Lower middle income
150 t/y	Low income

Product

Which products are contributing to the leakage?

Leakage in t/y	Nigeria	China	Bangladesh	United Kingdom	Germany	Oman
Milk		513		79	63	78
Milk powder	600	78	223	79	8	144
Cheese	95	20	131	113	126	
Butter		29		46	37	
Yoghurt				0	0	
Lactose					0	

The end-of-life leakage occurs mainly for milk, milk powder and cheese products

Which polymers are contributing to the leakage?

Polymer

Leakage in t/y	Nigeria	China	Bangladesh	United Kingdom	Germany	Oman
LDPE		431		99	46	184
Laminate	694	33	354	110	50	
PP	1	81		46	101	11
HDPE		59		25	8	9
PET		5		7	1	13
PS		25		11	6	4

The end-of-life leakage occurs mainly for LDPE and laminate packagings

Conclusions

Arla corporate activities generate 3'759 t/y plastic leakage, which corresponds to 4% plastic leakage intensity.

The plastic leakage over Arla's value chain mainly occurs when the product packagings are disposed (end-of-life), in countries where the waste can be mismanaged.

Key countries where packagings can be mismanaged are Nigeria, China and Bangladesh.

The end-of-life leakage occurs mainly for milk, powder and cheese products, and LDPE and laminate packagings.

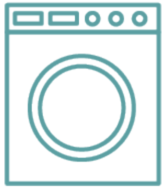
Sympatex case study

Key results

What is the total leakage along my value chain?

440 g
Macroplastic used
Jacket and losses: 420 g
Packaging: 20 g

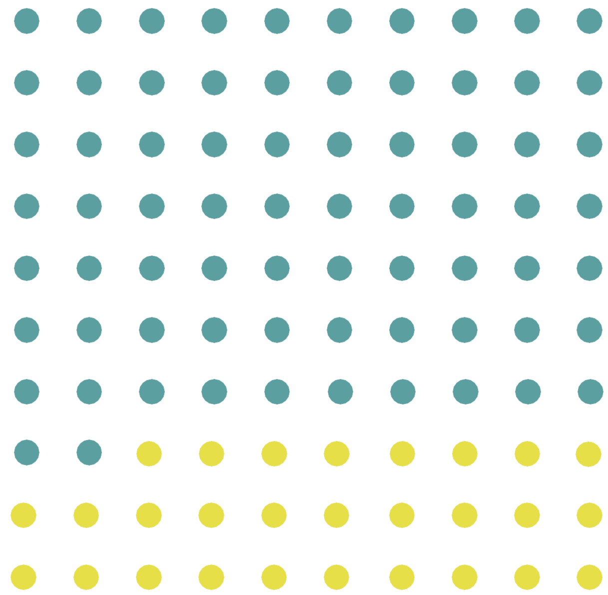
2'000 km
Road transport



360 g **Textile washed**

Equivalent to
5 times
during production

Equivalent to
10 times
during textile use



28% **Plastic leakage intensity**

6 g
Leakage into ocean
99% Macro

116 g
Leakage into other environmental compartments
99% Macro

Value chain

Where does the leakage occur along the value chain?

In which environmental compartment?

Suppliers
0.03 g

2-3%	Ocean
2-4%	Other terrestrial environment
76-79%	Soil
16-18%	Freshwater

Jacket production
0.6 g

6%	Ocean
91%	Other terrestrial environment
0.3%	Soil
2%	Freshwater sediments

Product End-of-life
121 g

5%	Ocean
95%	Other terrestrial environment

Transport
0.02 g

Product use (wearing)
0.03 g

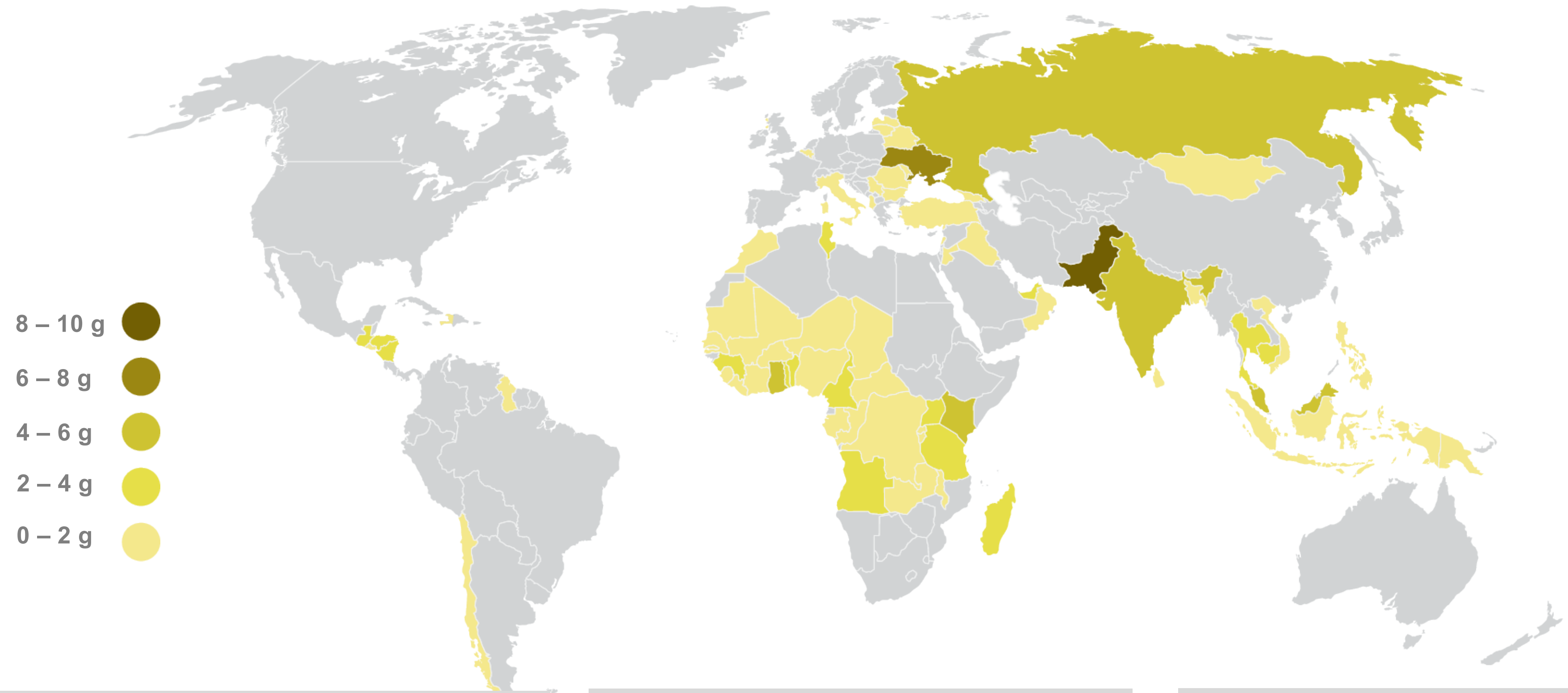
17%	Ocean
13%	Other terrestrial environment
16%	Soil
55%	Freshwater sediments

Leakage occurs mainly during the product end-of-life when the jacket is disposed

Country

In which country does the leakage occur?

Accounting for end-of-life plastic leakage where it occurs



50% of the collected textiles are considered to be exported for a second life

40% downcycled

10% incinerated

After their second life, they are considered to be treated as municipal solid, and are mismanaged if the waste treatment infrastructure is inadequate

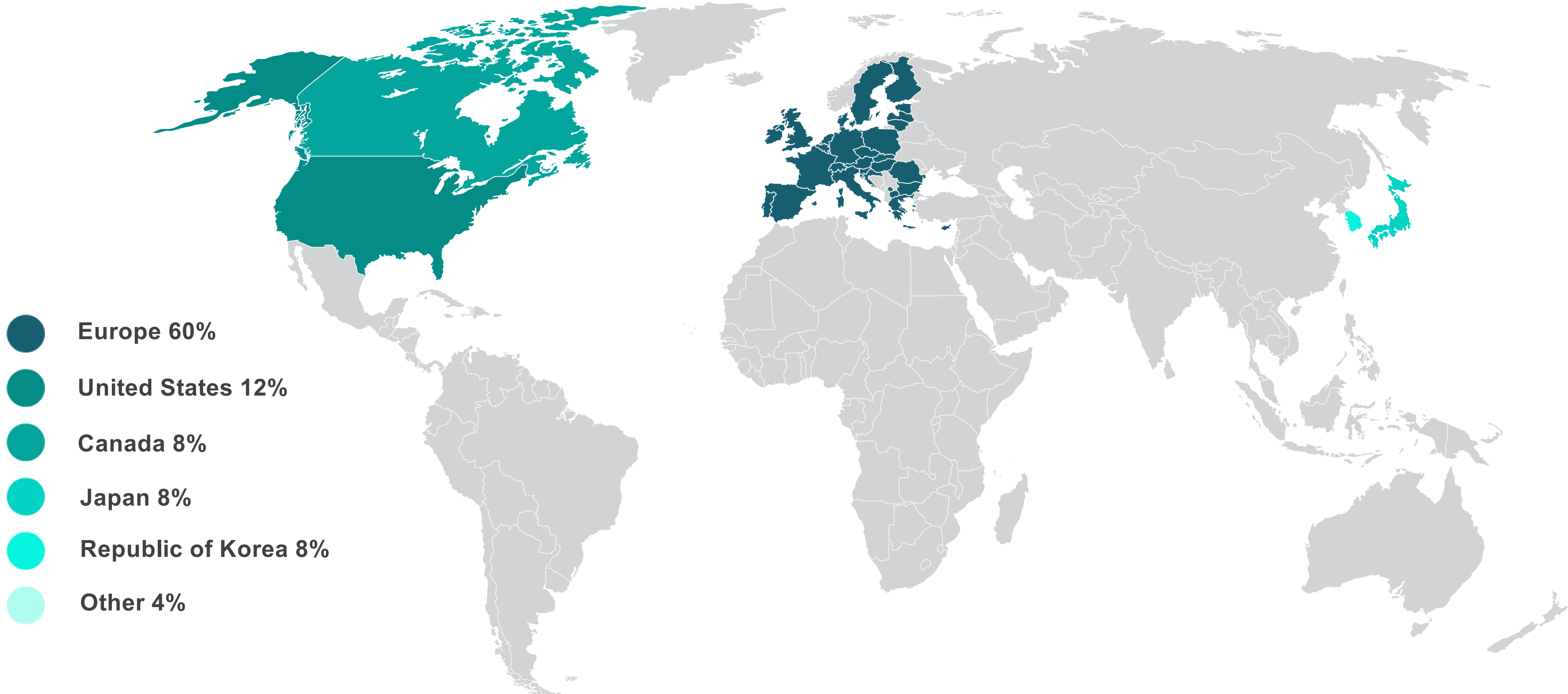
The end-of-life leakage occurs mainly in Africa, Asia and Eastern Europe

Source: Import countries for used clothes based on United Nations Statistical Division (COMTRADE) represented in https://oec.world/en/visualize/tree_map/hs92/import/show/all/6309/2017/

Market

Which market is responsible for the leakage?

Consumer responsibility view: the leakage is allocated on the basis of sales



The main jacket distribution markets are responsible for the leakage

Conclusions

This 3-layer hard shell outdoor jacket produced by Sympatex generates a leakage of 122 g, which corresponds to 28% plastic leakage intensity

The leakage occurs mainly during the product end-of-life when the jacket is disposed

After their second life, they are considered to be treated as municipal solid, and are mismanaged if the waste treatment infrastructure is inadequate

The end-of-life leakage occurs mainly in Africa, Asia and Eastern Europe

Quantis + ea

PLP co-founders include leading environmental sustainability consulting group **Quantis (quantis-intl.com)** and eco-design center **EA (shaping-ea.com).**

Project stakeholders represent a diversity of expertise and industries across the plastic value chain, as well as experts in micro-plastics, wastes, LCA and circularity, well-recognized academics exploring macro- and micro-plastics issues, renown international organizations for nature conversation, and the European Commission, linking this project with the on-going explorations on impacts of plastics.

Strategic Committee

Member Organizations

Advisory Committee

Discover the Plastic Leak Project
quantis-intl.com/plastic-leak-project
Download the PLP Guidelines at

quantis-intl.com/plastic-leak-project-guidelines

To find out more, contact Laura Peano, Plastic Leak Project Lead, Quantis