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Guiding Document V.2

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1. Introduction

This document was developed as part of the project Identifying and quantifying plastic contaminant sources and leakages into the aquatic environment, executed by UNEP International Environmental Technology Centre (UNEP-IETC) with support and cooperation of the European Commission Directorate-General for the Environment (DG ENV), and represents a further development upon the series of documents and materials being developed under the overall project implementation (Figure 1).

The main project's objective is to develop a practical methodology to identify and quantify sources of plastic pollution in the aquatic environment, allowing the production of an inventory of plastic pollution from a pollution source perspective, so that decisionmakers and control bodies can better understand current scenarios and develop strategies to address plastic pollution, with a particular interest on aquatic environments and focus on tailored actions according to pollution sources.

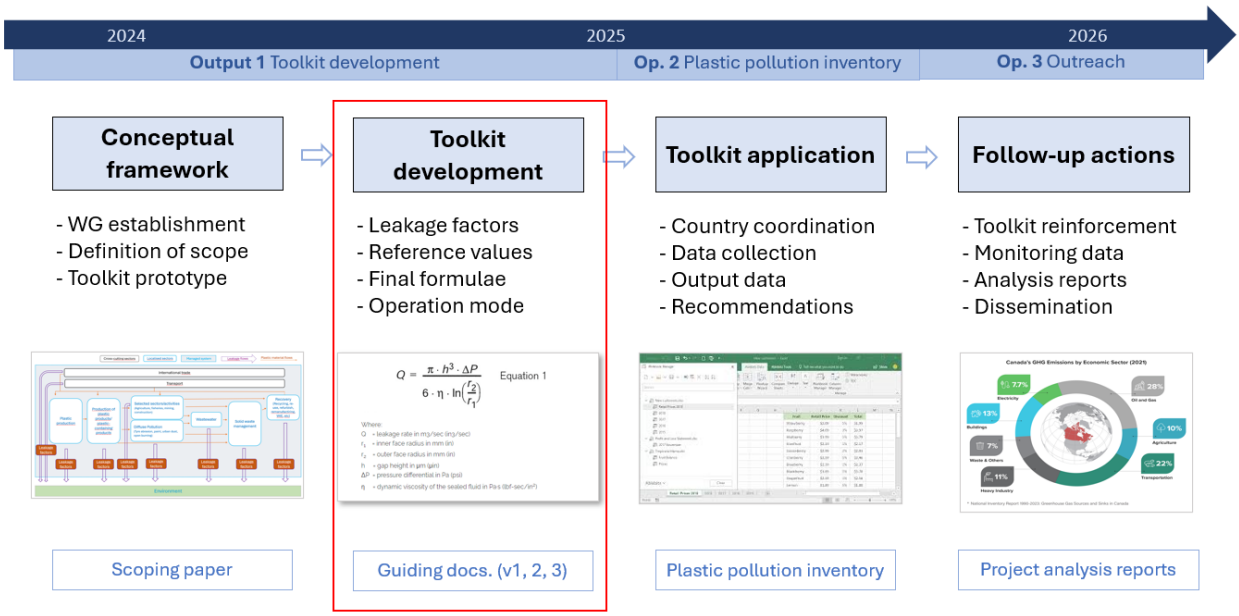


Figure 1. Overall project implementation plan

As outlined, this "Guiding Document version 2" (GD v2) is majorly built upon previous documents, such as the Guiding Document version 1 and others, which were developed with the support of a Working Group of experts (WG) and lay out the foundation for the development of a methodology to identify and quantify plastic pollution from a life cycle perspective, for a wide estimation (inventory) of plastic pollution across the plastic value chain. This methodology became the so-called **toolkit**, and this document illustrates how this toolkit will operate and what kind of output it will generate, in addition to

complementary actions upon the toolkit application, within the broad project implementation plan.

This GD v2 is also intended to be one of the **central materials underpinning the discussions of the 2nd WG meeting**,[1] which will primarily discuss the leakage factors here proposed, including their technical and scientific coherence and consistency with the project's objective.

2. Toolkit presentation

2.1 Objective

The proposed toolkit aims to be a quick assessment tool for an initial estimation of plastic pollution sources and flows running into the environment -an inventory. Its application should result in numerical estimates of plastic pollution flows running toward aquatic environments, from a source perspective and in a determined area at a certain time.

2.2 Toolkit framework

WG members and the project team converged that the toolkit should be comprised of leakage factors per source category, enabling the development of an inventory of plastic pollution in a determined area.

This is similar to the approach adopted by Zhu et al., (2024) who proposed a four-step approach for the development of a plastic pollution inventory, starting with the identification of major pollution sources and establishment of leakage factors, followed by the calculation of leakage flows and consideration of uncertainties and quality control measures (Figure 2).

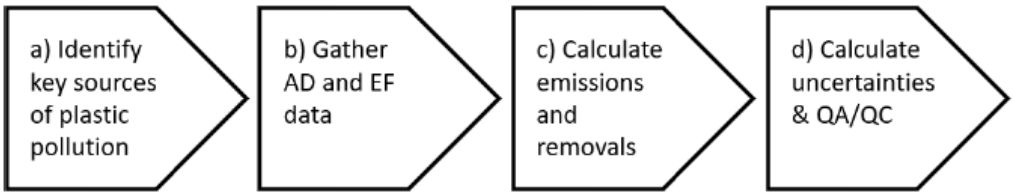


Figure 2. Generic framework for compiling and reporting emissions inventories of plastic pollution (methodology summarized). Extracted from Zhu et al., (2024)

[1] The 1st Working Group meeting was held in September 2024, with over 20 participants, including WG members, project team and UNEP and EC representatives. The 2nd meeting is planned to take place in July 2025.

Studies addressing plastic pollution tend to focus on the identification or quantification of plastic pollution flows from the perspective of plastic waste management practices, i.e., the fate of plastic materials according to waste management practices at their end-of-life (Amadei et al., 2023). Notwithstanding, plastic pollution is also known to occur across other stages of its life cycle, including production and consumption phases, which are estimated to account for roughly two-fifths of the total microplastic/plastic pollution leakage observed in Europe.[2] Therefore, the novelty proposed by this toolkit especially concerns the consideration of all stages of the plastics value chain, encompassing as many economic sectors and activities as possible.

In our conceptual framework, presented in the previous project documents, nine major sources of plastic pollution were proposed for the toolkit, where leakage flows are deemed either most likely or significant and with a division between localized and cross-cutting sectors, spanning across the four stages of the plastics life cycle (Figure 3). These source categories were defined mainly based on the dynamics of plastic material flows along its value chain (Amadei et al., 2025a) and different actors involved in each sector (Table 1).

Eight categories —international trade, transport, production, production of plastic products or plastic-containing products, selected sectors, wastewater, solid waste management and material recovery— refer to economic sectors, whereas one —diffuse microplastic pollution— denotes multi-faceted phenomena inherently associated with plastic pollution but where it is not possible to attribute the phenomenon to a specific sector or entity.

A category was named “selected sectors” to avoid clustering different sectors under a common “mismanaged” or “unmanaged waste” category. We decided instead to map major sectors (ETC HE Report, 2024) where plastic pollution is expected to occur within the consumption stage, considering that this would be comprehensive enough to account for the majority of microplastic leakage according to our proposed framework —even though many uncertainties still remain (Zhu et al., 2024).

This is relevant because one of our central assumptions is that the identification of the sector and/or locus where plastic pollution is believed to occur is a relevant aspect for policy action against plastic pollution. The only occasion where this (identification of actor/locus) was not possible was “diffuse microplastic pollution”, as explained in a previous paragraph.

[2] Ibid.

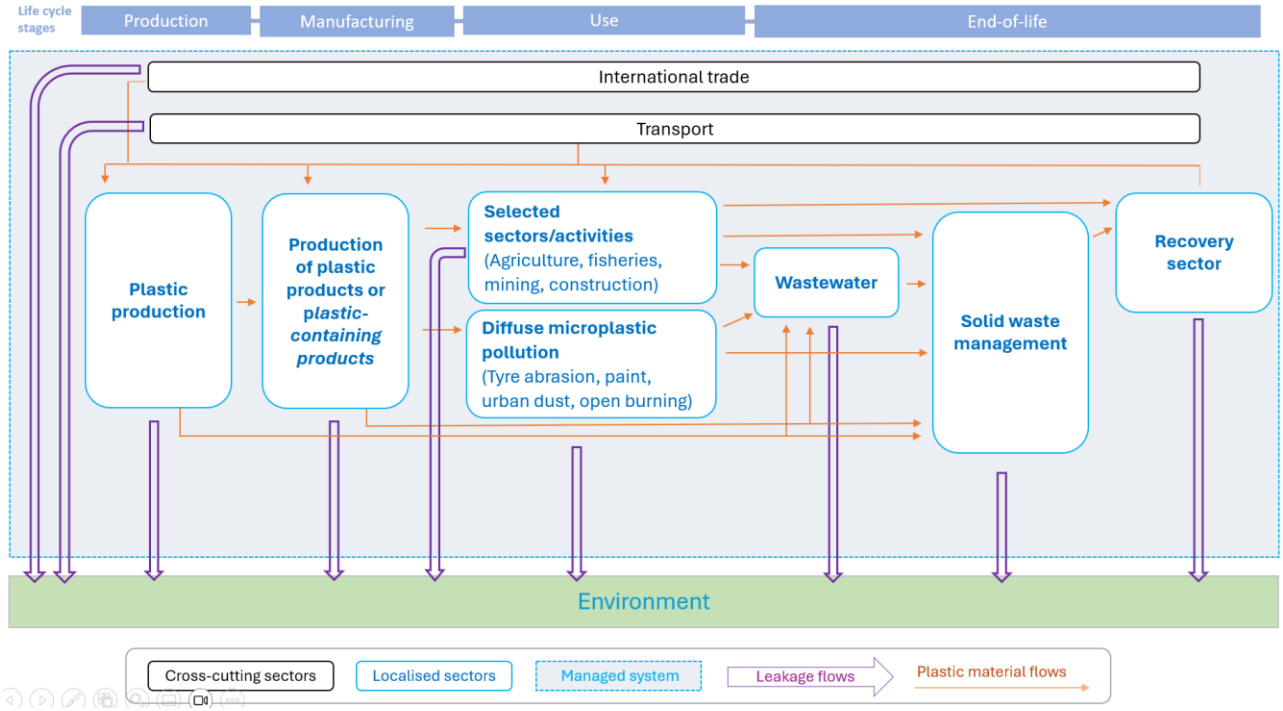


Figure 3. Toolkit's conceptual framework, showing source categories and plastic flows

Table 1. Leakage phenomena and main actors involved in each source category.

Plastic value chain sector (source categories)	How plastic pollution occurs	Main actors
Plastic production	Leakages during production and inadequate disposal	Petrochemical producer
Production of plastic products or plastic-containing products	Leakages during production and inadequate disposal	Converters, assemblers, manufacturer
Selected Sectors/Activities	Different leakage points observed in agriculture, fisheries, mining and construction sectors	Agriculture, fisheries, mining and construction stakeholders
Diffuse microplastic pollution	Leakages from tire abrasion, paint fragmentation, open burning, shoes sole fragmentation, and plastic surfaces dispersion or fragmentation	Retailers, consumers
Wastewater sector	Inefficiency in wastewater treatment	Wastewater management entities
Solid waste management	Leakages during collection, transportation and handling	Waste management stakeholders
Recovery sector	Leakages during recycling and Waste-to-Energy processes	Recycling and waste-to-energy stakeholders
International trade	Leakages during handling, storage, and movement of plastic materials	Trade and distribution stakeholders

Transportation	Leakages during handling, storage, and movement of plastic materials	Transportation companies

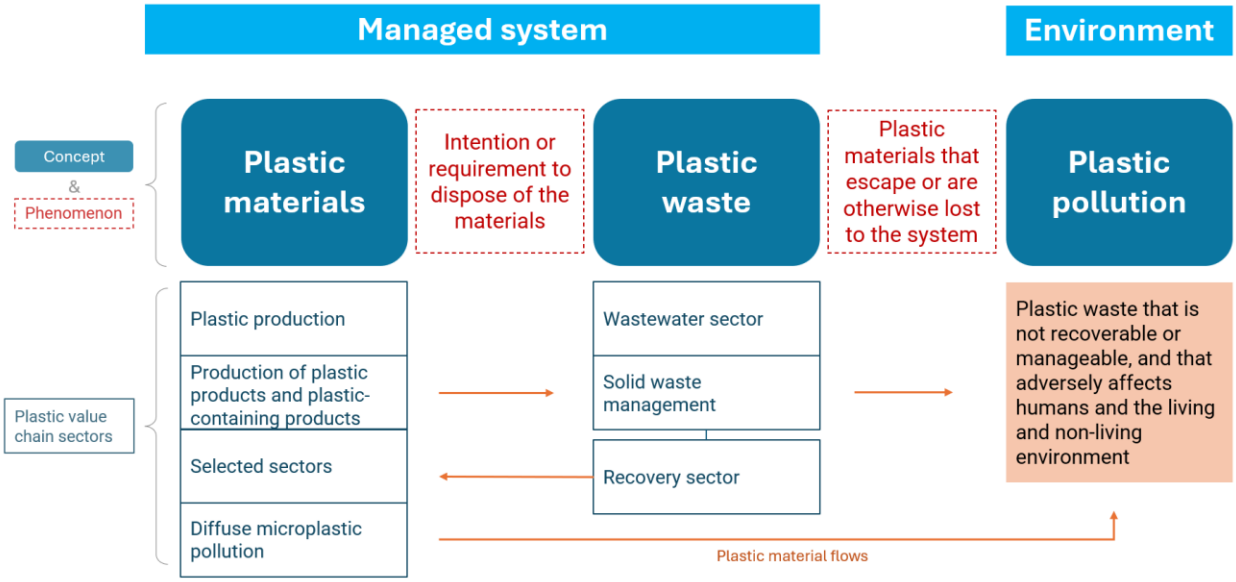
Based on: Hsu, Domenech and McDowall. Closing the loop on plastics in Europe: The role of data, information and knowledge. Sustainable Production and Consumption, Volume 33, 2022, Pages 942-951, ISSN 2352-5509, https://doi.org/10.1016/j.spc.2022.08.019. (Hsu et al., 2022)

For the definition of managed system, we follow Cottom, Cook and Velis (Cottom et al., 2024a), who establish three spheres according to the level (or lack) of management of plastic waste: managed, mismanaged and unmanaged. Based on that, "managed system" encompasses the authors' concepts of managed (controlled, contained) and mismanaged waste (subject to a form of control, however basic; contained state); whereas "environment" alludes to unmanaged waste (uncontrolled or uncontained, such as in the environment) —from a societal standpoint, it is when plastic materials are completely out of control or in an uncontained state; from an ecological perspective, we can refer to natural systems with low or no interference of humans and their activities (Jacobson et al., 2019).

As per the exact moment when a plastic material crosses these boundaries, we follow UNECE and UNITAR/UNEP, who establishes that plastic materials are considered to become waste when there is an "intention or requirement of holders to dispose of the materials", whereas plastic pollution refers to the negative effects and emissions resulting from the production and consumption of plastic materials and products across their entire life cycle (Figure 4). Therefore, our leakage factors refer to the transfer coefficients of plastics from the managed system to the environment, i.e., when plastic materials and/or plastic waste become plastic pollution.

A more detailed explanation about the toolkit's conceptual framework can be found in the previous project documents.[3]

[3] Available here: https://www.unep.org/ietc/events/working-group-meeting/2nd-working-group-meeting-unepec-project-identifying-and-quantifying.



Developed by the project team, based on UNECE (https://unece.org/statistics/publications/conference-european-statisticians-framework-waste-statistics) and UNEP (https://www.unep.org/resources/turning-off-tap-end-plastic-pollution-create-circular-economy).

Figure 4. Conceptual boundaries between plastic materials, plastic waste and plastic pollution

2.3 Toolkit operation

In scientific literature, a "toolkit" is generally defined as a collection of resources designed to translate theory into practice, often targeting a specific issue or audience. This may include knowledge materials, codification of best practices and methodologies to support policy action. Users are usually required to directly operate such toolkits, according to their needs and the information available (Yamada et al., 2015).

Against this background, this toolkit entails a methodology for the development of plastic pollution inventories from a pollution source perspective, with focus on the plastic pollution flows towards aquatic environments. On practical terms, we envisage a platform (software, application, web page…) where member states (usually people in governments dealing with environment, statistics and/or waste-related affairs) enter plastic-related data, rendering an inventory with the estimation of plastic materials leaving the managed system towards the environment, in certain territory and at determined timelapse, eventually highlighting the major sectors where plastic leakage may be occurring and shedding light on potential policy responses. Figure 5 depicts how this toolkit operation may look like, while Table 2 offers a classification of various toolkits

based on their core feature, with some examples, which may be useful for the decision on the final feature of the present toolkit.

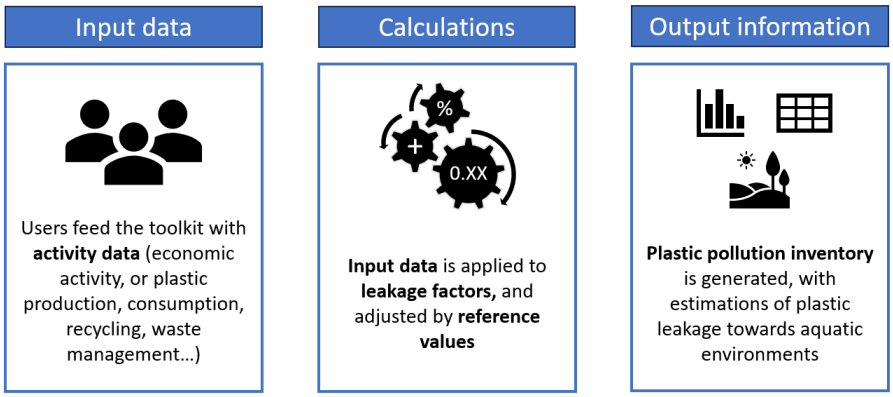


Figure 5. General representation of the toolkit's operation

Table 2. Examples of other toolkits or analogous initiatives aligned with the proposed toolkit

Type	Main features	Examples
Calculation tools	Tables, spreadsheets for calculation of environment-related coefficients	Mercury Inventory toolkit (UNEP, Minamata Convention)
Material flows	Flows of materials, energy or substances; Identification/quantification of amounts, sources and fates; Relationship between sectors/regions	Waste Flow Diagram (GIZ) Waste Wise Cities Tool (UN Habitat)
Infographics	Data translated into visual materials; Similar to material flows, but normally with additional information (recommendations, hotspots, data gaps, etc.)	Inventories of plastic pollution for national action plan in Mexico (Vázquez-Morillas et al, 2024) City-wide emissions inventory of plastic pollution (Zhu et al, 2024)
Spatial analyses	Pollution mapping and environmental pathways; Eventually with socioeconomic, political aspects	SPOT Model (Cottom, Cook & Velis, 2024) ISWA Plastic Pollution Calculator (ISWA and partners)
Benchmarks	Traffic light systems; Comparison and monitoring; Technical, governance aspects	Wasteaware benchmark indicators (DCW, RWA, University of Leeds)
Diagnoses	Coordinated approach for analysis of situation; Development of roadmaps and action plans based on codified knowledge	Sustainable Finance Diagnostic Toolkit (GGKP and UNDP)

Intervention guidance	Step-by-step instructions for targeted interventions; Usually at project-level	Breaking the Plastic Habit: A Guidance Note and Practical Toolkit (IGES)
Operation manual	How to use or interpret resources, platforms; Also for raising-awareness, capacity-building and networking engagement	Energy Transition Toolkit (World Energy Council)

Note: this is not an exhaustive list and the proposed categorization is not entirely exclusive, as many examples overlap across one or more categories.

As the toolkit's development advances, there will be discussions about the best platform or software to host its operation, including a possible combination of a frontend (for data entry and data visualization, e.g.) with back-end platforms (data calculations).[4]

To shed some light on the kind of output envisaged for this toolkit, we present a visualization of results obtained by three studies sharing a similar conceptual framework to ours (Figure 6). This may be seen as a reference only, subject to proper adjustments and specific adaptation according to the project's objective and its wide implementation plan upon the toolkit application (discussed in Chapter 3).

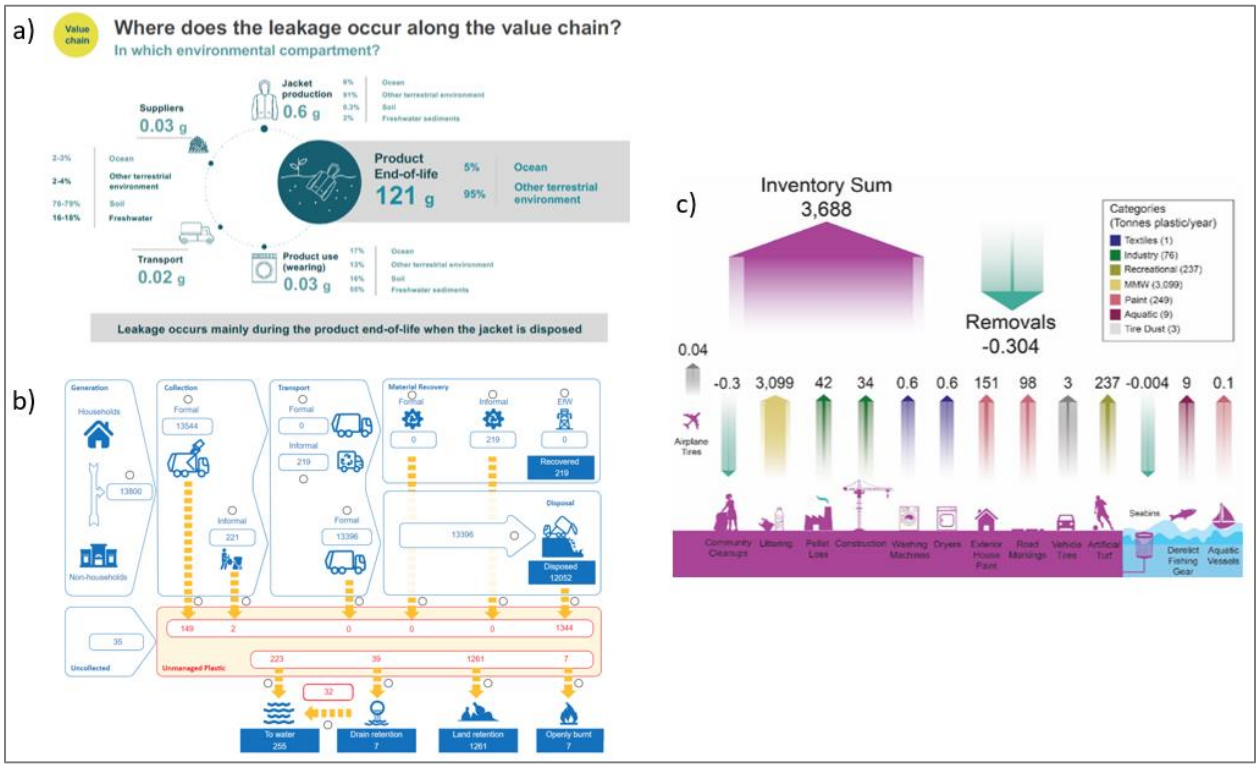


Figure 6. Examples of outputs as a reference for the toolkit

[4] Frontend platforms could be Excel, webpage or other online tools; backend applications could be R, Canvas, SPSS.

a) The Plastic Leak Project, led by Quantis and Earth Action. **b)** Waste Flow Diagram, GIZ (German Agency for International Development Cooperation), by Whiteman et al. 2023, https://www.giz.de/en/downloads/en-giz-wfd-compendium-2023.pdf. **c)** Zhu X, Hoffman MJ, Rochman CM. A City-Wide Emissions Inventory of Plastic Pollution. Environ Sci Technol. 2024 Feb 1. doi: 10.1021/acs.est.3c04348.

2.4 Leakage factors

The establishment of leakage factors for each source category relies on sufficiently detailed and reliable information regarding activity data, transfer coefficients and waste management practices. Given that the uncertainties and knowledge gaps are still many, the analyses and decisions that follow will be necessarily selective, with significant simplification and, sometimes, arbitrary assumptions. When the establishment of a leakage equation with a minimum consistency was rather too much stretchy,[5] we decided to opt for the exclusion of some categories.

It was the case of cross-cutting sectors. Trade and transport represent a potential source of significant plastic pollution (Kawecki & Nowack, 2019a), yet for not having well-defined material and spatial dynamics and for involving multiple jurisdictions with diverse standards and accounting mechanisms (Amadei et al., 2025b; ISO, 2024), we deemed it too complex to be captured by a single set of coefficients.

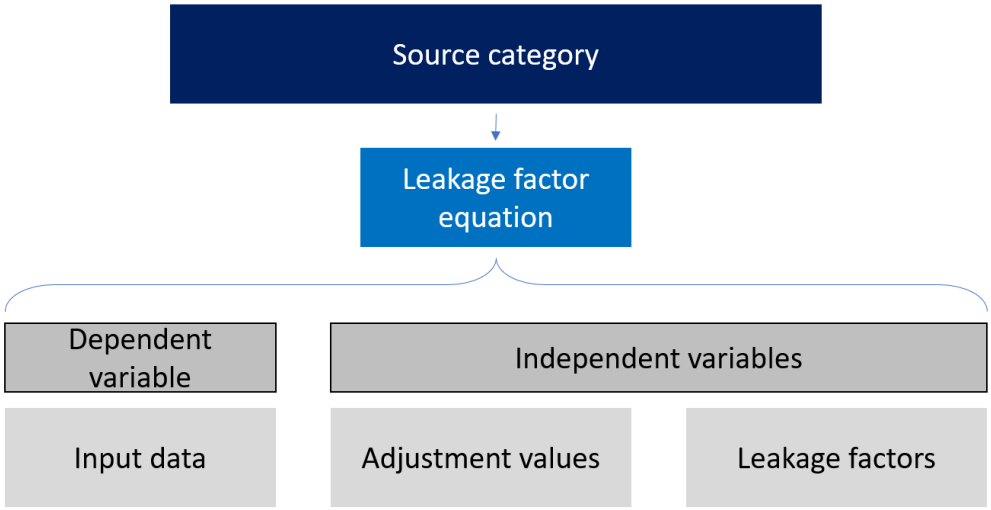


Figure 7. Leakage factor equations and sets of variables

Then, a main equation was proposed for each of the remaining source categories (or sub-categories, in some cases), composed of two main sets of variables: dependent and independent variables (Figure 7). The first one is the dependent variable and refers to the input data, to be provided by users, whereas the second comprises the independent part

[5] Either for a lack of complete understanding about the phenomenon (wide scientific community) or due to too many pieces of information that still require better and more data.

of the equation and is composed of (adjustment and leakage-related) coefficients to be applied upon the dependent variable.

Table 3. Master table with plastic pollution source categories, and details about leakage factors, reference values and sources

Source category	Sub-categories	Boundaries	Parameters[i]		
			Input data	Independent values	
				Adjustments values	Leakage factors
Production and manufacturing	Primary plastic production	Plastic materials handled by producers and manufacturers	Annual mass of plastic pellets produced, processed or handled		0,01% to 0,04 %
	Production of plastic products				
Agriculture	Mulching	Plastic materials used in each activity	Surface area with plastics	Retrieval rates[ii] 32% to 98%	(1 – retrieval rates)
	Greenhouses and tunnels			Collection rates 3% to 61%	(1 – collection rates)
	Irrigation		Area under irrigation system/silage activities	Application rate[iii] 400 kg/ha[iv] Retrieval rates 35% and 49%	(1 – retrieval rates)
	Silage tubes and bales			Application rate: 4.7 to 185 kg/ha Retrieval rates: 65% to 90%	(1 – retrieval rates)
Fisheries	Nets	Plastics used in fisheries activities	Gears deployed, no. of vessels, or fishing catch	Plastic mass of items Scarce information[v]	6% of items deployed
	Lines				29% of lines deployed (m)
	Pots and traps				9% of items deployed
Aquaculture		Plastic used in aquaculture activities	Plastic used (per farm, per cage, or per production)		0.13 kg to 0.18 kg per tonne harvested catch
Diffuse pollution	Artificial turf	Areas with synthetic turf field	Synthetic turf fields[vi] surface	Fiber density[vii] 1,300–1,700 g/m²	0.5% - to 10% per year
	Open burning	Plastic open burnt by target population	Plastic waste generation[viii]		0.07 to 0.4 kg/person/year
	Paints (architectural, maritime, road markings)	Painted surfaces	Painted surface areas	Application rate 0.15 to 0.8 kg/m²	23% to 71% within paint practical life[ix]
	Shoe soles	Walking/running distances by target population	Population		1.4 – 175 grams of microplastics/person /year
	Tyre	Distance travelled by the fleet	Distance travelled by the fleet	Plastic fraction in the thread: 35 to 60%[x]	45 – 658 mg per kilometre
Wastewater		Wastewater going though WWTPs	Volume of wastewater treated	Microplastic concentration 0.000067 to 10 mg/L	0.1 to 50%
Solid waste management	Collection	Plastic waste handled by waste sector within target area	Plastic waste generated	Plastic in solid waste composition 5% to 13%	6% to 45%
	Transportation				30% to 47%
	Sorting				2% to 6%
	Disposal				30% to 47%
Recovery sector	Mechanical recycling	Plastic handled by recycling facilities	Plastic waste received by recycling facilities[xi]	Sorting rate 65% to 91% Substitution factor 0.75 to 1	Plastic waste mismanagement applied to recycling/incineration residues
	Thermal recovery	Plastic burning in incineration plants	Plastics incinerated in incineration plants	Microplastics loss on ignition 2% to 4%	

[i] Fraction of the used plastic that is collected, recovered, or properly managed (recycled or disposed of) after use.
[ii] Plastic materials, such as irrigation pipes and drippers, utilized per hectare.
[iii] For irrigation tape.
[iv] One study suggests the average mass of a purse seine as 1,500kg.
[v] For countries not having granular information about field areas covered by artificial turf, an estimation based on the number of fields is provided, using average field sizes as a reference.
[vi] Weight of synthetic grass fibers per square meter.
[vii] For countries not having granular information, an estimation based on per capita plastic waste generation is provided.
[viii] Around 15-20 years for concrete and 8-10 years for wood, after Paruta et al, who ascertained that these are conservative estimates before a new repainting is done, assuming that this will only happen when the coating has reached 5%-10% of wear & tear losses.
[ix] Share of polymer fraction in the tyre tread, according to the type of vehicle (full table is provided below, in the due section).
[x] In case no data is available, an estimation can be derived from the recycled materials effectively processed for the manufacturing of new products, according to the substitution factors between recycled and virgin material

Adjustment values are intended to adjust or align the equation according to the reality or specific conditions of each source category, whereas leakage factors generally reflect the estimated percentage of plastic that escapes into the environment.

Based on this, Table 3 offers a brief description of proposed equations and their proposed parameters for the source categories which we decided to consider in the toolkit. A narrative with the full development of these factors can be found in Annex 1.

2.5 Data collection and data requirements

Narrative explaining what kind of data would be required, and how and where countries could get it

Data Requirements for Plastic Leakage Factors Development

Plastic pollution modelling along the plastics value chain requires robust, reliable, and interoperable data to enable the development of meaningful plastic leakage factors. However, current datasets are often fragmented, heterogeneous in quality, and geographically limited, which requires a pragmatic approach to data selection and treatment.

The data requirements for the establishment of leakage factors vary depending on the sector being analyzed. For example, sectors like *plastic production* and *plastic product manufacturing*, reliable data on production volumes, process losses, and material handling practices are essential. In *agriculture*, *fisheries*, and *construction* sectors, sector-specific usage patterns of plastic materials, quantities and type of production (in terms of hectares or agriproducts) product life cycles, and end-of-life practices must be characterized. For *solid waste management* and *material recovery* sectors, detailed statistics on collection rates, treatment technologies, and mismanagement pathways are necessary. Similarly, for diffuse sources like *tire abrasion* and *paint degradation*, activity data (vehicle use and distances, paint surface areas) are crucial.

Across all sectors, datasets must meet minimum standards of robustness, meaning they should be based on sufficiently large sample sizes or validated methodologies to avoid biased extrapolations. Reliability is equally critical: datasets should originate from verifiable sources, including government statistics, standardized surveys, academic publications, and reviewed technical reports. Whenever possible, national statistics offices, international organizations, and environmental monitoring programs will be prioritized as primary data sources. In the absence of direct measurements or specific values, references values and uncertainty levels derived from case studies or similar methodologies will be offered.

Interoperability of data is fundamental to allow adaptation across different modelling contexts. Therefore, compatibility with recognized environmental frameworks will be necessary conditions for dataset selection.

In light of the expected scarcity of comprehensive data in many developing countries—the main focus of the toolkit—flexibility in data handling, transparency in assumptions, and again, uncertainty level indications will be necessary to safeguard model coherence and the reliability of the estimation of plastic leakage.

Table 4 offers a panorama of types of data needed for the toolkit operation, in addition to source suggestions and related examples. (work to be completed in the further version)

Table 4. Data required and possible data sources

Data types needed	Useful for	Possible sources	Example
Amount of plastic produced within a country and type of technology and /or polymer	Estimation of leakages from plastic production processes	National Statistics. Plastic producers' associations.	
Amount of generated wasted, composition (percentage of plastic), level of collection and type of disposal	Estimation of Plastic leakages within the solid waste management systems.	National / sub national governments. Collection companies. Other sources: International reports such as GWMO.	

2.6 Target audience

This toolkit is primarily aimed at UN Member States that have limited capacity to identify and quantify sources of plastic pollution entering the aquatic environments. The end users may be government officials working in national statistical offices, particularly on

divisions more closely related to environmental and waste or pollution affairs, whereas the generated information is primarily intended to inform high-level policymakers.

At international level, the toolkit may also be relevant for the design of strategies and action plans for entities such transboundary river and lake basin organizations and Regional Seas Conventions; not to mention its potential to be used for monitoring or accounting purposes under global agreements, such as Basel Convention or eventually the Global Plastic Treaty, which is currently in its final stage of negotiations.

The information then generated may be used by decision-makers for policy action addressing plastic pollution and proper plastic waste management, whereas civil society (river basin committees, regional fisheries bodies, NGOs, citizens, etc.) may use the knowledge generated by the toolkit to underpin their activities concerning the matter, or even for local and global advocacy against plastic pollution.

Finally, this toolkit may also be of interest to civil society (river basin committees, regional fisheries bodies, NGOs, citizens, etc.) for their own activity planning and overall awareness-raising purposes, and to academy practitioners, scientists and other individuals and entities dealing with or interested in plastic pollution research.

2.7 Uncertainties and limitations

Our study has a lot of limitations and uncertainties. In short, assumptions were made to reduce complexity while still allowing the toolkit to generate useful information in line with the project's objective; whereas the toolkit only provides a rough indication of plastic pollution flows and these estimates come with a large degree of uncertainty.

As examples of assumptions, we assumed the same leakage rate for converters and manufacturers, despite clear, significant differences between the sectors; and we oversimplify the complex, multifaceted scenario of plastic recycling into a plain depiction of a mechanical recycling facility, to be able to clearly identify boundaries for the leakage factor. A better explanation can be found in Annex 1, where the development of equations is presented.

Furthermore, a risk assessment such as the one here proposed should ideally distinguish between each kind of material and their characteristics, since life cycle, release pathways and, therefore, leakage factors might differ significantly according to that; exposure and toxicity factors may also be different depending on the materials (Kawecki & Nowack, 2019b). Nonetheless, we chose to keep the focus on the big picture, i.e., on pieces of information with more potential to explain the results, rather than focusing on very detailed data.

Various strategies can be applied to identify and provide remedy to these uncertainties and limitations, ranging from mathematical techniques (error propagation method, Monte Carlo simulations) (Zhu et al., 2024) to discretionary evaluations (experts elicitation, Fuzzy logic method) (Adu et al., 2025; Cottom et al., 2024c), among others. Perhaps of most importance and practical for the present toolkit, we tried to avoid data information from unknown or unchecked sources and rely also on the iterations and discussions provided by the Working Group to reinforce these decisions.

We anticipate that in some cases we may be compelled to use data from unclear sources or methods, to which we may use some simple strategies to deal with such inconsistencies, such as data quality rankings (Zhu et al., 2024) (Table 5), that allow the quantification (or classification) of the uncertainty of collected information to offer a broader yet more consistent range of estimated values (Meijer et al., 2021), or the establishment of different versions of the toolkit, according to the level and quality of available information (UNEP, 2023).

Table 5. Example of data quality ranking accounting for uncertainties

Data characteristics	Data uncertainty ranges
Primary data from national statistics, well-documented national surveys and industrial data or personal communications with possibilities for verification and validation	±5%
Data from documented national or regional surveys, with few independent sources to validate, that strongly rely on expert judgements or assumptions	±20%
Data largely based on assumptions and/or highly aggregated statistics with little verification	±50%

Adapted from: Lobelle et al., 2023. Knowns and unknowns of plastic waste flows in the Netherlands.

Such data and methodological challenges are not unique to this project, as essentially all similar initiatives are facing equivalent challenges, either for measuring, modelling and interpreting plastic pollution data (Blettler et al., 2018), so further validation models and reinforcing activities —such as the own toolkit pilot application and the environmental monitoring studies— may be likewise considered after and during the toolkit application.

2.8 What this toolkit is not intended to cover

This toolkit is not intended to be a new method or model, but rather a rapid assessment tool based on existing models, methods and available information.

Due to time and technical constraints, it will focus on the estimation of overall plastic leakage along the plastic value chain. Thus, chemical, biological and physical parameters (macro-, micro-, nano; fragment, fiber, nurdle, etc.) are not expected to be differentiated in the toolkit's outputs, nor will different plastic waste streams (plastic types, hardness,

colour), plastic applications (textile, packaging), plastic types (PP, PET…) and chronological aspects (plastic lifetime).

In the same vein, impacts of plastic pollution on humans and societies are beyond the toolkit's scope, thus aspects linked to toxicity, sociology, climate change, biodiversity, etc. will not be considered (some of these elements may be addressed further in the project though, as detailed in Section 3).

Finally, the toolkit intends to simply identify points where plastics pollution is expected to occur, not necessarily entailing any implication to the responsible(s) or the responsibility for such phenomenon (e.g. WWTPs receive and treat plastic waste that is generated by other sectors up in the value chain).

3. Project follow-up

As outlined in the introduction, the development and the application of this toolkit comprise two of the three components forming part of the overall implementation of the project "Identifying and quantifying plastic contaminant sources and leakages into the aquatic environment". Therefore, various other activities may follow the toolkit's application, either for the toolkit reinforcement itself or to provide additional analytical information in contribution to the project.

Environmental monitoring is one of these areas, which can help us understand how plastic moves and accumulates in different environments, while enabling also the linkage of plastic pollution phenomenon to its sources, according to the type and specific location of litter. Spatial and socioeconomic data can provide additional insights, allowing also the evaluation of the success of interventions throughout the time.

The toolkit reinforcement is another planned activity, aiming to identify the lessons learnt and the "knowns and unknows" that may emerge from the toolkit application. Table 6 summarizes these and other ideas, all subject to further consideration upon the toolkit application.

Table 6. Potential follow-up actions upon the toolkit application

Topic	Sub-topic	Contribution to the project	Examples/references
Environmental monitoring	Fate of pollutants	Understand the dynamics of plastics (pathways) in nature, particularly in aquatic environments	Rivers as Plastic Reservoirs
	Pollution modelling	Connection of plastic pollution with pollution sources	High-Resolution Mapping of Japanese Microplastic and Macroplastic Emissions from the Land into the Sea

	Monitoring programmes	Analysis of historical data to identify/build trends related to plastic pollution	European Coastline Macro Litter Trends 2015 - 2021
Policymaking	Mitigation scenarios	Baseline inventories for the identification of priorities and timeline for source-reduction	A city-wide emissions inventory of plastic pollution
	Development action plans		Navigating Plastic Management Tools for Government Action Planning
	Threshold values	Establishment of ecological threshold values for legal and regulatory frameworks	Marine Litter Threshold Values
	Footprint analysis	(Narrative connecting w GEF proj)	
	Regional pollution mapping	Understand intra- and interregional dynamics of plastic pollution	A local-to-global emissions inventory of macroplastic pollution
	Pollution mapping	Heat mapping of plastic pollution for land planning	GIS mapping of agricultural plastic waste in southern Europe
Human health	Human exposure to plastics	Identify effects from plastic pollution at individual, inter and intra individual and populational level	Weight of Evidence for the Microplastic Vector Effect in the Context of Chemical Risk Assessment
	Toxicity of plastics		Potential Health Impact of Microplastics: A Review of Environmental Distribution, Human Exposure, and Toxic Effects
Technical aspects	Toolkit reinforcement	(check prodoc)	
	Thesaurus and ontology	Contribution to harmonization efforts on concepts and phenomena	GPML Communities of Practice on data harmonization
	Guidelines for pollution analysis	Contribution to the harmonization of litter categories	Joint List of Litter Categories Manual
	Data and knowledge gaps	Contribution to reducing information gaps and flagging critical “unknowns”	Why we need a packaging and waste data revolution

This table is merely illustrative, as many of these topics and activities can or should be addressed together.

4. Next steps

This “Guiding document version 2” builds upon the previous documents[6] developed under the project “Identifying and quantifying plastic contaminant sources and leakages into the aquatic environment”, as well as the technical iterations between WG members

[6] Guiding document v1: https://www.unep.org/ietc/events/working-group-meeting/2nd-working-group-meeting-unepec-project-identifying-and-quantifying

and the project team. It presents a first complete proposal for the leakage factors for the toolkit application and the production of a plastic pollution inventory.

This material is also the foundational document for the 2nd WG meeting that may take place in mid-2025, which will primarily discuss the leakage factors here proposed and their consistency to the toolkit development and the project's objective. Once this is concluded, the project may enter its second stage, comprising the coordination with the country for toolkit's pilot application and the continuation of the project implementation (Figure 8).

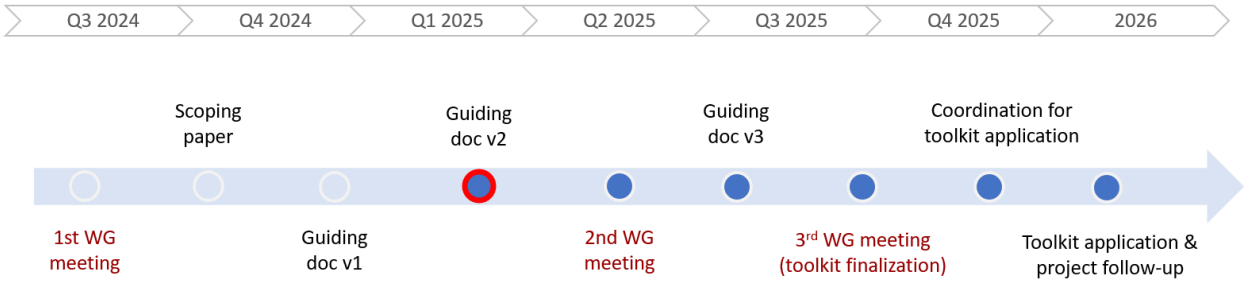


Figure 8. Timeline with next steps

This detailed timeline aligns with the overall project implementation plan, presented in the Introduction.

5. Contact

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Project's website: https://www.unep.org/ietc/what-we-do/plastic-waste-management/eu-funded-project-sustainable-plastic-waste-management

*** This document received AI assistance for its production, mostly from *ChatGPT* and *Copilot* models.

6. References

Acarer, S. (2023). Microplastics in wastewater treatment plants: Sources, properties, removal efficiency, removal mechanisms, and interactions with pollutants. *Water Science and Technology*, *87*(3), 685–710. https://doi.org/10.2166/wst.2023.022

Adu, T. F., Mensah, L. D., Rockson, M. A. D., & Kemausuor, F. (2025). Decision support systems for waste-to-energy technologies: A systematic literature review of methods and future directions for sustainable implementation in Ghana. *Heliyon*, *11*(3), e42353. https://doi.org/10.1016/j.heliyon.2025.e42353

Amadei, A. M., Rigamonti, L., & Sala, S. (2023). Exploring the EU plastic value chain: A material flow analysis. *Resources, Conservation and Recycling*, *197*, 107105. https://doi.org/10.1016/j.resconrec.2023.107105

Amadei, A. M., Rigamonti, L., Tosches, D., & Sala, S. (2025a). Combining MFA and LCA models to unveil the EU plastic value chain impacts. *Resources, Conservation and Recycling*, *219*, 108279. https://doi.org/10.1016/j.resconrec.2025.108279

Amadei, A. M., Rigamonti, L., Tosches, D., & Sala, S. (2025b). Combining MFA and LCA models to unveil the EU plastic value chain impacts. *Resources, Conservation and Recycling*, *219*, 108279. https://doi.org/10.1016/j.resconrec.2025.108279

APE Europe. (2025). Statistics. *APE Europe*. https://apeeurope.eu/statistics/

Blettler, M. C. M., Abrial, E., Khan, F. R., Sivri, N., & Espinola, L. A. (2018). Freshwater plastic pollution: Recognizing research biases and identifying knowledge gaps. *Water Research*, *143*, 416–424. https://doi.org/10.1016/j.watres.2018.06.015

Bø, S. M., Bohne, R. A., Aas, B., & Hansen, L. M. (2020). Material flow analysis for Norway's artificial turfs. *IOP Conference Series: Earth and Environmental Science*, *588*(4), 042068. https://doi.org/10.1088/1755-1315/588/4/042068

Bø, S. M., Bohne, R. A., & Lohne, J. (2024). Environmental impacts of artificial turf: A scoping review. *International Journal of Environmental Science and Technology*, *21*(16), 10205–10216. https://doi.org/10.1007/s13762-024-05689-3

Castillo, M. (2024). *Silage and Haylage Production | NC State Extension Publications*. https://content.ces.ncsu.edu/forage-conservation-techniques-silage-and-haylage-production

Chimenos, J. M., Segarra, M., Fernández, M. A., & Espiell, F. (1999). Characterization of the bottom ash in municipal solid waste incinerator. *Journal of Hazardous Materials*, *64*(3), 211–222. https://doi.org/10.1016/S0304-3894(98)00246-5

Cottom, J. W., Cook, E., & Velis, C. A. (2024a). A local-to-global emissions inventory of macroplastic pollution. *Nature*, *633*(8028), 101–108. https://doi.org/10.1038/s41586-024-07758-6

Cottom, J. W., Cook, E., & Velis, C. A. (2024b). A local-to-global emissions inventory of macroplastic pollution. *Nature*, *633*(8028), 101–108. https://doi.org/10.1038/s41586-024-07758-6

Cottom, J. W., Cook, E., & Velis, C. A. (2024c). *Plastic pollution emission factors: How much escapes, how far it goes, and how to intervene in the solid waste management system*. Research Square. https://doi.org/10.21203/rs.3.rs-4850420/v1

ETC HE Report. (2024). *Microplastic releases in the European Union*. Eionet Portal. https://www.eionet.europa.eu/etcs/etc-he/products/etc-he-products/etc-he-reports/etc-he-report-2024-15-microplastic-releases-in-the-european-union

FAO. (2021). *Assessment of agricultural plastics and their sustainability: A call for action*. FAO. https://doi.org/10.4060/cb7856en

GESAMP. (2015). *Sources, fate and effects of microplastics in the marine environment: A global assessment*. ResearchGate. https://doi.org/10.13140/RG.2.1.3803.7925

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, *3*(7), e1700782. https://doi.org/10.1126/sciadv.1700782

Hitchcock, J. N. (2020). Storm events as key moments of microplastic contamination in aquatic ecosystems. *Science of The Total Environment*, *734*, 139436. https://doi.org/10.1016/j.scitotenv.2020.139436

Hsu, W.-T., Domenech, T., & McDowall, W. (2022). Closing the loop on plastics in Europe: The role of data, information and knowledge. *Sustainable Production and Consumption*, *33*, 942–951. https://doi.org/10.1016/j.spc.2022.08.019

ISO. (2024). *ISO policy brief: Combatting plastic pollution with International Standards*. ISO. https://www.iso.org/publication/PUB100483.html

Jacobson, A. P., Riggio, J., M. Tait, A., & E. M. Baillie, J. (2019). Global areas of low human impact ('Low Impact Areas') and fragmentation of the natural world. *Scientific Reports*, *9*(1), 14179. https://doi.org/10.1038/s41598-019-50558-6

Kawecki, D., & Nowack, B. (2019a). Polymer-Specific Modeling of the Environmental Emissions of Seven Commodity Plastics As Macro- and Microplastics. *Environmental Science & Technology*, *53*(16), 9664–9676. https://doi.org/10.1021/acs.est.9b02900

Kawecki, D., & Nowack, B. (2019b). Polymer-Specific Modeling of the Environmental Emissions of Seven Commodity Plastics As Macro- and Microplastics. *Environmental Science & Technology*, *53*(16), 9664–9676. https://doi.org/10.1021/acs.est.9b02900

Kuczenski, B., Vargas Poulsen, C., Gilman, E. L., Musyl, M., Winkler, B., & Geyer, R. (2022). A model for the intensity of fishing gear. *Journal of Industrial Ecology*, *26*(6), 1847–1857. https://doi.org/10.1111/jiec.13156

Laura Peano, Anna Kounina, Violaine Magaud, Sophie Chalumeau, Melissa Zgola, & Julien Boucher. (2020, February 27). The Plastic Leak Project Guidelines. *Quantis*. https://quantis.com/reports/the-plastic-leak-project-guidelines/

Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Science Advances*, *7*(18), eaaz5803. https://doi.org/10.1126/sciadv.aaz5803

Müller, A., Österlund, H., Marsalek, J., & Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. *Science of The Total Environment*, *709*, 136125. https://doi.org/10.1016/j.scitotenv.2019.136125

Richardson, K., Hardesty, B. D., Vince, J., & Wilcox, C. (2022). Global estimates of fishing gear lost to the ocean each year. *Science Advances*, *8*(41), eabq0135. https://doi.org/10.1126/sciadv.abq0135

Säberg, M. (2021). *Sustainability of Artificial Turf Fields*. https://www.diva-portal.org/smash/get/diva2%3A1578484/FULLTEXT01.pdf

Skirtun, M., Sandra, M., Strietman, W. J., van den Burg, S. W. K., De Raedemaecker, F., & Devriese, L. I. (2022). Plastic pollution pathways from marine aquaculture practices and potential solutions for the North-East Atlantic region. *Marine Pollution Bulletin*, *174*, 113178. https://doi.org/10.1016/j.marpolbul.2021.113178

Steinmetz, Z., Löffler, P., Eichhöfer, S., David, J., Muñoz, K., & Schaumann, G. E. (2022). Are agricultural plastic covers a source of plastic debris in soil? A first screening study. *SOIL*, *8*(1), 31–47. https://doi.org/10.5194/soil-8-31-2022

Sugiura, M., Takada, H., Takada, N., Mizukawa, K., Tsuyuki, S., & Furumai, H. (2021). Microplastics in urban wastewater and estuarine water: Importance of street runoff. *Environmental Monitoring and Contaminants Research*, *1*, 54–65. https://doi.org/10.5985/emcr.20200006

Sundan, S. M. B., Michelsen, O., Rasmussen, F. N., Aas, B., & Bohne, R. A. (2025). Dynamic material flow analysis of microplastics lost from artificial turfs: A case study from

Norway. *Science of The Total Environment*, *973*, 179159. https://doi.org/10.1016/j.scitotenv.2025.179159

UNEP. (2023). *Mercury Inventory Toolkit | UNEP - UN Environment Programme*. https://www.unep.org/topics/chemicals-and-pollution-action/pollution-and-health/heavy-metals/mercury/mercury-inventory

Yamada, J., Shorkey, A., Barwick, M., Widger, K., & Stevens, B. J. (2015). The effectiveness of toolkits as knowledge translation strategies for integrating evidence into clinical care: A systematic review. *BMJ Open*, *5*(4), e006808. https://doi.org/10.1136/bmjopen-2014-006808

Yang, Z., Lü, F., Zhang, H., Wang, W., Shao, L., Ye, J., & He, P. (2021). Is incineration the terminator of plastics and microplastics? *Journal of Hazardous Materials*, *401*, 123429. https://doi.org/10.1016/j.jhazmat.2020.123429

Zhu, X., Hoffman, M. J., & Rochman, C. M. (2024). A City-Wide Emissions Inventory of Plastic Pollution. *Environmental Science & Technology*, *58*(7), 3375–3385. https://doi.org/10.1021/acs.est.3c04348

Annex 1: Compilation of plastic leakage factors

A1.1 Plastic production: production of plastic products and plastic containing products

Context

This section assumes a single approach either to produce plastic products and the manufacturing of plastic or plastic-containing products, with an emphasis on pellet leakage.

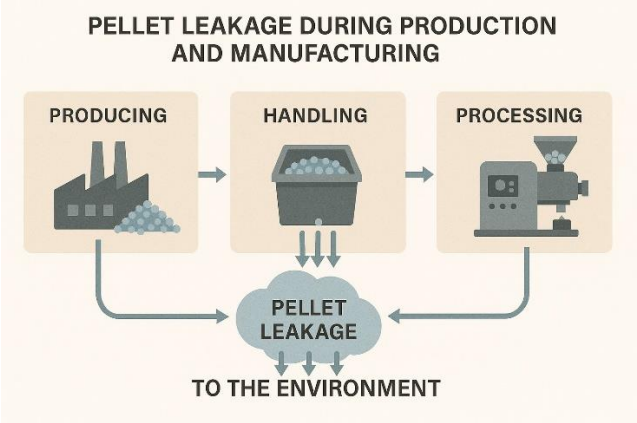

Figure 9. Leakage pathways in production and manufacturing. AI-generated.

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 (GESAMP, 2015), and normally serve as the raw material for manufacturing plastic products. During various stages of the production chain, these plastic pellets may inadvertently be released into the environment during various stages of production and manufacturing chains (Figure 9).

Proposed equation

Plastic leakage plastic production = plastic mass produced, handled or processed x leakage factors during production, transportation and processing, or

$$PLpm = PP\ (L_p + L_s + L_{pr})$$

Where:

- $PLpm$: Annual plastic leakage from plastic production and manufacturing (kg)
- PP: Annual mass of plastic pellets produced, processed or handled (kg or tons)
- LFp: Leakage factor during production
- LFh: Leakage factor during handling (supply/transport/storage)
- $LFpr$: Leakage factor during processing

Reference values

Plastic produced, processed or handled: input data

Leakage factor during production, supply/transport/storage, and processing: 0,01% to 0,04% (Laura Peano et al., 2020) (at each stage)

Sources

Sundt, P., & Schulze, P.-E. (2015). *Sources of microplastic-pollution to the marine environment.* (Mepex Report for the Norwegian Environment Agency) https://www.miljodirektoratet.no/globalassets/publikasjoner/m321/m321.pdf

https://plasticseurope.org/plastics-explained/how-plastics-are-made

Koehler, Angela & Anderson, Alison & Andrady, Anthony & Arthur, Courtney & Baker, Joel & Bouwman, Hindrik & Gall, Sarah & Hidalgo-Ruz, Valeria & Koehler, Angela & Law, Kara & Leslie, Heather & Kershaw, Peter & Pahl, Sabine & Potemra, Jim & Ryan, Peter & Shim, Won & Thompson, Richard & Takada, Hideshige & Turra, Alexander & Wyles, Kayleigh. (2015). SOURCES, FATE AND EFFECTS OF MICROPLASTICS IN THE MARINE ENVIRONMENT: A GLOBAL ASSESSMENT. http://dx.doi.org/10.13140/RG.2.1.3803.7925

Peano et al., The Plastic Leak Project Guidelines https://quantis.com/reports/the-plastic-leak-project-guidelines/

A1.2 Selected sectors

A1.2.1 Agriculture - Main activities, products and applications

Context

Agricultural plastics that are not collected for separate recycling or formal disposal may enter terrestrial and aquatic ecosystems through three main mechanisms: damaged, degraded or discarded; known by FAO as the “3D concept” (FAO, 2021). Therefore, the quantification of plastic leakages requires a multi-factorial approach, given the variety of plastic usages in the sector, which may be defined by the usage intensity and used amount (e.g. kg/ha for mulching films, or m²/ha for greenhouses), as well as degradation rates (physical, chemical biological) and management practices (collection and recycling efficiencies).

Based on reference literature and data availability, we identified four main subcategories to be considered in this category, according to their plastics application: mulching, greenhouses and tunnels, irrigation, and silage tubes and bale wraps; which is believed to account for up to 50 percent of global usage (FAO, 2021). In this context, both collection and degradation rates will be the central components in our proposed equations; with the latter being more challenging to find.

A1.2.1.1 Plastic mulching

Plastic mulches are widely used in agriculture to cover soil, control weeds, conserve moisture, and regulate soil temperature (Figure 10).

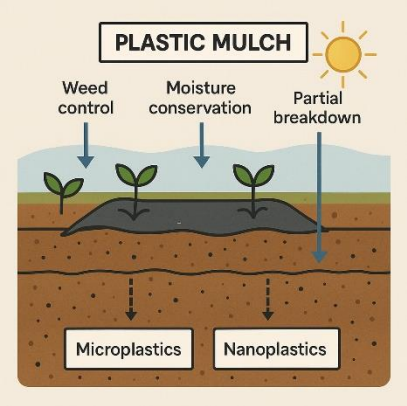

Figure 10. Plastic mulching in agriculture and leakage pathways. AI-generated.

Such covers are suspected of partially breaking down into smaller debris and thereby contributing to soil pollution with microplastics (Steinmetz et al., 2022). According to Briassoulis (2023) micro and nano-plastics (MNP) generation by mulching films highly depends on geographical region, materials, cultivations, agriculture plastic waste (mis)management.

Proposed equation

Plastic leakage plastic mulching = Area x Usage rate x Retrieval rate, or

$$PL_{mulching} = A \times Ap \times (1 - R)$$

Where:

- $PL_{mulching}$: Annual plastic leakage from mulching activities (kg)
- A: Total area (m2 or ha) where plastic mulch is applied.
- Ap: Application rate. Plastic used in mulching activities, typically measured in kilograms per hectare per year (kg/ha) or in total kilograms applied across a region.
- R: fraction of the used plastic that is collected, recovered, or properly managed (recycled or disposed of) after use.

Reference Values

Area: input data

Application rate

Table 7. Plastic mulching application rates, per region

Region	Application rates (kg/hectare)
Europe (Average)	185
Asia (Average)	63

South and North America	10 – 20

Source: Deconinck, S. 2018 in FAO 2021

Retrieval rate: the thickness of the mulching films influences their probability to being recovered or being removed from the soil, as illustrated in the table below.

Table 8. Mulching films retrieval rates according to film thickness

Region	Film thickness (µm)	Estimated mulching plastic retrieved from the field (%)
Europe (Average)[7]	20- 25	90 - 98
Asia (Average)	8	32
South and North America	10	32

Source: Deconinck, S. 2018 in FAO 2021

A1.2.1.2 Greenhouses and tunnels

Greenhouses, walk-in high tunnels and low tunnels are used to extend the growing season in the temperate regions of the world, while in tropical regions they enable crop production during the rainy or monsoon seasons. According to Le Moine (2018), they represent the largest quantity of plastic films used in plant production, and similarly to mulch films, they likewise inevitably degrade over time, due to factors such as exposure to ultraviolet light, temperature fluctuations and mechanical stresses. Hence, collection rates are again a key parameter for the equation.[8][9]

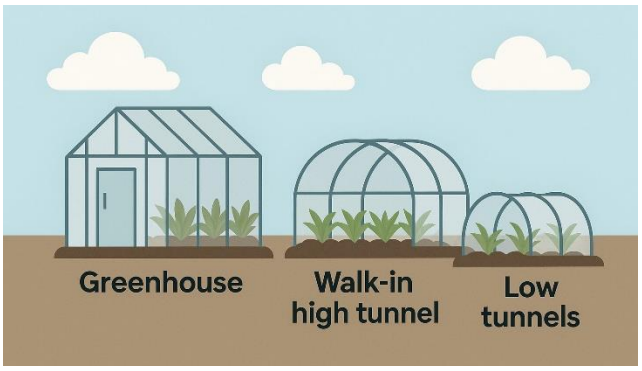

Figure 11. Greenhouses and tunnels used in agriculture. AI-generated.

[7]For a case analyzed (Spain) it was considered that the use of plastic for mulch films is 250 kg per hectare. https://openknowledge.fao.org/server/api/core/bitstreams/d1b18314-562a-48bc-83d6-90610cdd6257/content

[10] https://qampo.es/academy/cultivos-protegidos-e-invernaderos/

[10] https://qampo.es/academy/cultivos-protegidos-e-invernaderos/

Proposed equation

$$PL_{gh\&tunnels} = A \times U\ (1-R) \times LF_d$$

Where:

- $PL_{gh\&tunnels}$ = Annual plastic leakage from greenhouses and tunnels activities (kg)
- A = Surface area covered with plastic in greenhouses and tunnels in certain year (m² or ha)
- U = Usage Rate (The quantity of plastic materials (mass) utilized per hectare (kg/ha)
- R = Retrieval of plastics used in greenhouse and tunnels (fraction, between 0 and 1)
- LF_d = Leakage factor representing plastic degradation and loss rate (kg/m²)

Reference values

Area: input data.

In case no data is found, the below data can be used as proxy estimates, however, country-specific data are recommended.

Table 9. Estimated areas under greenhouses and cultivation tunnels, per countries and regions

Country/Region	Estimated area covered (ha)	Description/complementary comments	Plastic film Usage (kg/ha)
Global	450,000[10]	Total greenhouse area (excluding tunnels); small share of ag. land	3,500 (global average) [11]
China	60.4% of global total[12]	Largest share globally; dominant greenhouse user	
Asia (China, Japan, Korea)	80% of Global total [13]	Largest regional share when including greenhouses and high tunnels	
Mediterranean Basin	30% of >450,000 ha[14]	Second-largest regional share	
Spain	5.6% of global total[15]	Among top countries globally	

[10] https://qampo.es/academy/cultivos-protegidos-e-invernaderos/
[11] https://openknowledge.fao.org/server/api/core/bitstreams/d1b18314-562a-48bc-83d6-90610cdd6257/content
[12] https://qampo.es/academy/cultivos-protegidos-e-invernaderos/
[13] https://openknowledge.fao.org/server/api/core/bitstreams/d1b18314-562a-48bc-83d6-90610cdd6257/content
[14] https://phys.org/news/2024-06-satellite-reveals-global-bloom-greenhouse.html
[15] https://phys.org/news/2024-06-satellite-reveals-global-bloom-greenhouse.html

Italy	4.1% of global total[16]	Among top countries globally	

***LF degradation and loss rate*:** No data available.[17]

Retrieval rate: Values for collection rates were found.

Table 10. Collection rates of plastics used in greenhouses and tunnels, per global region

Region	Collection rate %
Europe	61
South America	58
North America and Oceania	40
Africa	21
Asia	3

Source: http://dx.doi.org/10.1016/j.scitotenv.2023.164533

Potential reference values (Europe)

In the EU, recycling rates are around 28 per cent, with 30 per cent incinerated and 42 per cent sent to landfill. Recycling rates vary between countries, with Ireland achieving 63 per cent, whereas Bulgaria, Romania, Slovenia and Slovakia report zero per cent. Where plastics are not recovered, they are often buried in the soil, abandoned in fields or watercourses and even illegally burnt[18] but all these values are applied to all agriculture plastics.

A1.2.1.3 Irrigation (Tape, tubes and drippers)

Plastic-based irrigation systems, such as drip irrigation, utilize components like irrigation tapes, tubes, and drippers to deliver water directly to plant roots (Figure 12), thereby enhancing water efficiency and crop yields.[19]

[16] https://phys.org/news/2024-06-satellite-reveals-global-bloom-greenhouse.html

[17] FAO´s 3D approach assigns a value of 3, 2 and 1 regarding the potential for leakage into the environment at site of use: Damaged and Degraded, respectively applied to Greenhouse Films. This means that Greenhouse films show a level of medium risk to be damaged and a low level of risk to be degraded. However, this three-level range is not enough to perform a reference value. According to FAO (2021), agricultural plastics that are not collected for separate recycling or formal disposal may enter terrestrial and aquatic ecosystems through any one of three main mechanisms: namely, through being damaged, degraded, or discarded. This has been termed the '3D concepts'. Plastics that are damaged, degraded or discarded in the environment are sometimes referred to as 'leaked plastics' (Boucher and Billard, 2019) and "mismanaged plastic" (Jambeck et al., 2015) and this has been the focus of much research in recent years (Richardson, Hardesty and Wilcox, 2019; The Pew Charitable Trusts and SYSTEMIQ, 2020).

[18] https://eia-international.org/wp-content/uploads/Fields-of-Plastics-FINAL.pdf#:~:text=EU%2C%20recycling%20rates%20are%20around,This

[19] https://www.fao.org/4/s8684e/s8684e07.htm

Figure 12. Agricultural pipes made of plastics. Source: Extracted from ori-plast.

Proposed equation

Plastic leakage irrigation = Area x application rate x Retrieval rate x Degradation rate, or

$$PL_{\text{irrigation}} = A \times Ap \times (1-R) \times LF_d$$

Where:

- *PL irrigation*= Annual plastic leakage from irrigation activities (kg/year)
- A= Surface area covered with irrigation systems in certain year (m² or ha)
- Ap=application rate (the quantity of plastic materials, such as irrigation pipes and drippers, utilized per hectare, kg/ha)
- R= Retrieval of plastics used in the irrigation systems (fraction, between 0 and 1)
- D=Plastic degradation rate (kg/m²)

Reference values

Application rate: input data.

In case no granular data is found, the below data can be used for proxy estimation:

- According to APE Europe, 2019, 6% of agriculture plastic use corresponds to irrigation (APE Europe, 2025),
- FAO estimates that around 400 kg of plastics are used per hectare as irrigation tape (there are no specific values for irrigation tubes) (FAO, 2021).

Retrieval

Table 11. Reference values for plastic collection related to irrigation

Country / Region	Retrieval

France	35%[20]
Europe	49.5%[21]

Source: Briassoulis and EIA (https://irrigationeurope.eu/en/a-new-scheme-for-recycling-flexible-irrigation-tube/; https://doi.org/10.1016/j.wasman.2013.03.004)

Degradation: There is a lack of scientific reference values for the Degradation Factors. However, we leave the equation as it is, in case countries may count with some data on degradation and therefore on the different plastic fates (air, water or soil accumulation).

A1.2.1.4 Silage tubes and Bale Wraps

Silage films are plastic covers used in livestock farming to promote anaerobic fermentation of fodder, preserving its nutritional value without needing large infrastructure. They block air and moisture to ensure proper fermentation and come in various forms: clamp covers, single-use tube bags, and bale wraps (FAO, 2021). Although essential for preserving fodder quality, durable clamp films used for silage are usually damaged by poor handling, while single-use tubes and bale wraps often become contaminated with farm waste, hindering recycling (FAO, 2021).

Proposed equation

Plastic leakage Silage = Application area x application rate x degradation x recovery rate, or

$$PL_{silage} = A \times U \times D \times (1-R)$$

Where:

- PL_{silage}: Annual plastic leakage from silage activities (tubes and Bale Wraps) (kg/year)
- A: area where silage activities occur (m2 or ha)
- U: application rate of plastic materials used per ha (kg)
- D: Degradation Rate (0-1)
- R = Retrieval rate (Collection, Recovery, recycling and proper disposal rate of used plastics - fraction, between 0 and 1)

Reference values

Area: input data.

Application rate

[20] https://irrigationeurope.eu/en/a-new-scheme-for-recycling-flexible-irrigation-tube/
[21] General value for all agriculture plastics in Europe.https://doi.org/10.1016/j.wasman.2013.03.004

Table 12. Plastic application rates in silage

Type of silage	Country/Region	(Plastic) Usage (kg/ha)
Clamp Silage	Europe	4.7 (kg/ha)[22]
Baled Silage	Global average	23.5 (kg/ha)[23]
Silage Films	Europe	185 (kg/ha)[24]
Silage films	Quebec - Canada	69% of total agricultural plastics[25]

Degradation and loss rate: limited evidence was found, suggesting that most silages have an average single use duration of 6 to 12 months (Castillo, 2024).[26]

Retrieval (Collection/Recovery)

Collection and Recovery values for silage are difficult to find. Notwithstanding, based on studies carried out in Germany, Ireland and Canada (below), we recommend the following range values:

Lower bound: 65%

Upper bound: 90%

Table *13*. *Case studies on plastic retrieval data points regarding silage and bale activities*

Germany	68% of silage and stretch films collected.[27]
Ireland	18 million silage bales recycled in 2022 (37,000t of silage wrap and silage pit covers) an 88% recycling rate for all farm plastics, predominantly silage wrap.[28]
Canada	three-year average recovery rate of 78% (2021–2023) for major agricultural plastics—including silage bags, bale wrap, grain bags, and twine.[29]

Sources

C. Bisaglia, E. Tabacco, G. Borreani, The use of plastic film instead of netting when tying round bales for wrapped baled silage, Biosystems Engineering, Volume 108, Issue 1, 2011, Pages 1-8, ISSN 1537-5110, https://doi.org/10.1016/j.biosystemseng.2010.10.003

[22] https://doi.org/10.3920/9789086865536_006
[23] https://doi.org/10.3920/9789086865536_006
[24] https://doi.org/10.17660/ActaHortic.2019.1252.10
[25] https://openknowledge.fao.org/server/api/core/bitstreams/d1b18314-562a-48bc-83d6-90610cdd6257/content
[26] https://www.papillons-h2020.eu/wp-content/uploads/2021/12/Plastics-in-agriculture-sources-and-impacts-UNEP-GRID-Arendal.pdf
[27] https://newsroom.kunststoffverpackungen.de/en/2023/05/16/erde-recycling-sammelt-68-prozent-silo-stretchfolien-2/
[28] https://www.agriland.ie/farming-news/farmers-recycle-18m-silage-bales-worth-of-plastic-in-2022/
[29] https://farmonaut.com/canada/farm-plastic-recycling-in-canada-2-2-million-kg-collected-in-2024

Briassoulis D. Agricultural plastics as a potential threat to food security, health, and environment through soil pollution by microplastics: Problem definition. Sci Total Environ. 2023 Sep 20;892:164533. doi: 10.1016/j.scitotenv http://dx.doi.org/10.1016/j.scitotenv.2023.164533

D. Briassoulis, M. Hiskakis, E. Babou, Technical specifications for mechanical recycling of agricultural plastic waste, Waste Management, Volume 33, Issue 6, 2013, Pages 1516 1530, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2013.03.004

Cassou,Emilie. *Plastics (English).* Agricultural Pollution Washington, D.C. : World BankGroup. http://documents.worldbank.org/curated/en/122161521208357388

De Souza Machado, A. A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M. C. (2018). *Microplastics as an emerging threat to terrestrial ecosystems*. Global Change Biology, 24(4), 1405–1416. https://doi.org/10.1111/gcb.14020

European Irrigation Association (EIA) https://irrigationeurope.eu/en/a-new-scheme-for-recycling-flexible-irrigation-tube/

Forristal and O'Kiely , Update on technologies for producing and feeding silage, https://doi.org/10.3920/9789086865536_006 https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=5055&context=igc

Martin Henseler. Plastic emissions from mulch film and abatement measures - a model-based assessment for Germany. 2022. ffhal-03779834v2f https://hal.science/hal-03779834v2/document

Hofmann, T., Ghoshal, S., Tufenkji, N. *et al.* Plastics can be used more sustainably in agriculture. *Commun Earth Environ* **4**, 332 (2023). https://doi.org/10.1038/s43247-023-00982-4

Haihe Gao, Changrong Yan, Qin Liu, Weili Ding, Baoqing Chen, Zhen Li, Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis, Science of The Total Environment, Volume 651, Part 1, 2019, Pages 484-492, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.09.105

Hann, S., Fletcher, E., Molteno, S., Sherrington, C., Elliott, L., Kong, M., Koite, A., Sastre, S., & Martinez, V. (2021). *Conventional and biodegradable plastics in agriculture: Final report*. European Commission, DG Environment. https://environment.ec.europa.eu/system/files/202109/Agricultural%20Plastics%20Final%20Report.pdf

Le Moine, B. and Ferry, X. (2019). Plasticulture: economy of resources. Acta Hortic. 1252, 121-130 DOI: 10.17660/ActaHortic.2019.1252.17 https://doi.org/10.17660/ActaHortic.2019.1252.17

Monica C.M. Parlato, Francesca Valenti, Simona M.C. Porto, Covering plastic films in greenhouses system: A GIS-based model to improve post use sustainable management, Journal of Environmental Management, Volume 263, 2020, 110389, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2020.110389

Razza, F., Guerrini, S. and Impallari, F.M. (2019). How sustainable biodegradable and renewable mulch films are? A quantitative approach in the light of sustainable development goals. Acta Hortic. 1252, 77-84, https://doi.org/10.17660/ActaHortic.2019.1252.10

Rogers, E. E. (2014). Plastic Silage Film Recycling: A Business Plan. University of Kentucky, IGC Proceedings

Steinmetz Z, Wollmann C, Schaefer M, Buchmann C, David J, Tröger J, Muñoz K, Frör O, Schaumann GE. Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation? Sci Total Environ. 2016 Apr 15;550:690-705. https://doi.org/10.1016/j.scitotenv.2016.01.153

United Nations Environment Programme, GRID-Arendal. *Plastics in agriculture: Sources and impacts*. Working Paper. Nairobi: United Nations Environment Programme; 2021. https://www.papillons-h2020.eu/wp-content/uploads/2021/12/Plastics-in-agriculture-sources-and-impacts-UNEP-GRID-Arendal.pdf

A1.2.2 Fisheries

Context

In wild-capture fisheries, plastic "leakage" comes primarily from fishing gear – nets, lines, ropes, traps, floats, etc.- that are lost due to accidents (e.g. storms, snags) or improper disposal. Three major gear categories will be considered in this context: nets (gillnets, seine nets, trawls), lines (longlines and fishing lines) and pots and traps (Figure 13).[30] Researchers comparing fisheries could use "kg of plastic lost per tonne of fish caught" as a standardized indicator.

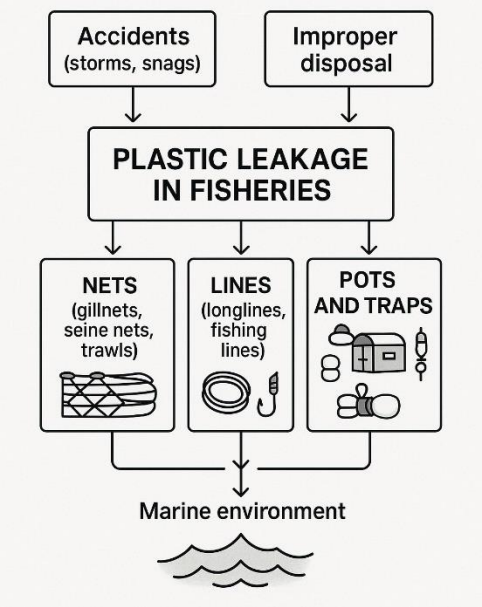

Figure 13. Plastic leakage in fisheries activities. Source: AI-generated.

The EIA report provides values in both units and mass, while Richardson et al. focus on proportions and gear sizes. Although some studies report total losses in kilograms or tons, comparing losses by mass can be misleading because gear types vary greatly in weight. For instance, fishing lines and hooks weigh much less than large nets or traps. Therefore, using proportions, sizes, or counts of gear lost offers a more consistent and meaningful way to compare gear loss across types (Richardson et al., 2022). In this regard, to quantify and compare leakage, it may be useful to express gear losses in standardized units. Below there are a proposed set of simple metrics and reference

[30] https://eia-international.org/wp-content/uploads/2023-EIA-UK-Agriplastics-Report-Fishing-Gear-SINGLES.pdf

values (per vessel, per gear unit, and per production output) for the fishing and aquaculture sectors, supported by current global and regional data. However, following EIA approach, when possible, mass units (mainly for vessels) are presented in parallel with other units of measurement.

Proposed equation

Plastic Leakage fisheries = material used × average plastic mass of each item × leakage factor, or

$$PL_{\text{fisheries}} \text{ (nets, lines, and pots and traps)} = Mat \times PM \times LF$$

Where:

- $PL_{\text{fisheries}}$: Annual plastic leakage from fisheries activities (kg or Tn)
- *Mat*: Materials deployed annually (Nets: net/year or net/vessel/year; Lines: total length or number of lines x average length items/year; Pods and traps: Number of pots or traps/year)
- *PM*: Average plastic mass of items (Nets: kg/no. of nets; Lines: kg/m; Pots and traps: kg/no. of items)
- *LF*: Fraction of materials lost to the environment per year (%)

Reference values

Materials: input data (whether specific data on fishing gears deployed in the target area or number of vessel or fishing catch data)

Plastic mass of items: Plastic mass of gears depends on the type of gear. At the time this document had been built, we found no comprehensive or specific value (Kuczenski et al., 2022).[31] One paper suggests that the average mass of a purse seine could be 1500 kg (Kuczenski et al., 2022).

Taking as a reference a unit of measurement of mass of plastic leaked/mass of fish caught, and based on the above data, a ballpark figure is on the order of 0.5–1.0 kg of lost fishing gear per tonne of catch globally, though this can be much higher in some fisheries (and lower in well-managed ones).[32]

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[31] An indirect approach was given by Kuczenski et. al when explaining the concept of "effort intensity". "The rate at which the gear is lost into the environment, known as a "dissipation rate." "The dissipation rate reports the fraction of the gear's total mass that is lost to the sea over a given operating time. There may be several distinct forms of environmental dissipation, including principally gear abandonment, loss, and discard. Dissipation of gear = Mass of gear · Dissipation rate · Operating time" https://doi.org/10.1111/jiec.13156

[32] cciced.eco

Leakage factor

Table 14. Leakage factors of plastics used in fisheries, global rates, per item and per vessel values, according to gear categories

Gear category	Global rate	Per item	Per vessel	Comments/Other reference values
Nets	~5.7% lost per year	~0.06 per net per year. 1 net per 15–20 deployments (approx.)	Tens to hundreds of kg of netting lost per vessel-year (depending on gear used). Example: Norway ~380 t total from ~1,900 vessels ≈ 200 kg/vessel	If summing values expressed in Richardson et al (2022), the whole value is: 10,59 %.
Lines	~29%	~290 m per 1000 m used per year. 1 net per 15–20 deployments (approx.)	Dozens of km of line lost per vessel-year in longline fisheries. For a large longliner: 100–300 kg line lost yearly (est.)	If summing values expressed in Richardson et al (2022), the whole value is: 9,77 %.
Pots and traps	~8.6% lost per year	~0.09 traps lost per trap-year (9% chance). ~9 lost per 100 deployed	Several traps lost per vessel-year. E.g. 5–10 traps (5–10% of gear) lost annually for a typical trap fisher, equating to ~20–50 kg of plastic (ropes, parts)	Values expressed in Richardson et al (2022), are: 0,77 %.

Source: Environmental Investigation Agency UK (2023) with data from Richardson et al (2022)

A1.2.3 Aquaculture

Context

Similar to fisheries, multiple factors drive plastic leakage in aquaculture, due to inter alia the exposure of aquaculture installations to ultraviolet light, biofouling and saltwater degradation, in addition to weather events and even the nibbling of fish or other organisms (Figure 14). In addition, farm workers may unintentionally drop or deliberately discard plastic items into the bottom of rivers, ponds and ocean (Skirtun et al., 2022). Plastic usage and leakage factors are thus the main variables for this category, under three different accounting approaches (plastic used either per farm, per cage or structure, or per catches or production), aiming to cover all aquaculture activities in a given territory, contingent to data availability.

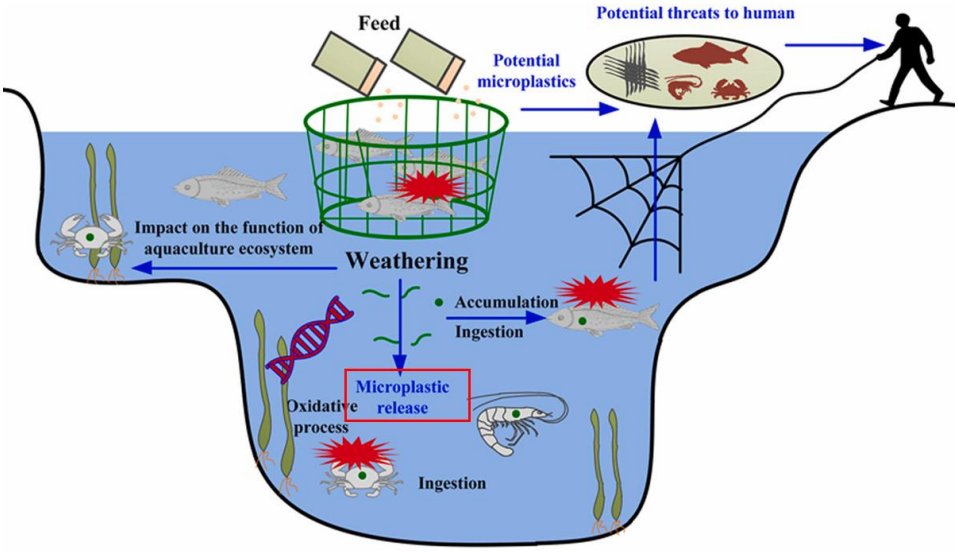


Figure 14. Characterization of potential microplastic releases in aquaculture activities. Source: Extracted from Miao et al., (2023)

Proposed equation

Plastic leakage aquaculture = total plastic used x leakage factor, or

$$PL_{aquac} = TP \times LF$$

Where:

- PL_{aquac}: Annual plastic leakage from aquaculture activities (kg/year)
- TP: total plastic used (per farm, per cage or structure, or per catch or production)
- LF: percentage of plastic (per farm, per cage or structure, or per catch or production) lost to the environment

Reference values

Plastic used: input data.

Leakage factor

Table 15. Leakage factors in aquaculture activities, per farm, per cage/structure, and per catch/production

Per farm	n/a
Per cage, structure	n/a
Per catch, production	0.13 kg of discarded plastic per tonne harvested fish (FAO, 2021)[33] 0.18 kg of discarded plastic per tonne harvested catch (EIA)[34]

[33] https://openknowledge.fao.org/server/api/core/bitstreams/d1b18314-562a-48bc-83d6-90610cdd6257/content
[34] https://eia-international.org/wp-content/uploads/2023-EIA-UK-Agriplastics-Report-Fishing-Gear-SINGLES.pdf

Sources

Katrina Bornt, Jason How, Simon de Lestang, Kathryn Linge, Renae Hovey, Tim Langlois, Plastic gear loss estimates from a major Australian pot fishery, ICES Journal of Marine Science, Volume 80, Issue 1, January 2023, Pages 158–172, https://doi.org/10.1093/icesjms/fsac222

Environmental Investigation Agency UK. (2023). Cultivating plastic: Preventing plastic pollution in the fisheries and aquaculture supply chain. Environmental Investigation Agency. Retrieved from https://eia-international.org/wp-content/uploads/2023-EIA-UK-Agriplastics-Report-Fishing-Gear-SINGLES.pdf

Kuczenski, B., Poulsen, C. V., Gilman, E. L., Musyl, M., Geyer, R., & Wilson, J. (2021). Plastic gear loss estimates from remote observation of industrial fishing activity. Fish and Fisheries. https://doi.org/10.1111/faf.12596

Kuczenski, B., Vargas Poulsen, C., Gilman, E. L., Musyl, M. K., Winkler, B., & Geyer, R. (2022). A model for the intensity of fishing gear. Journal of Industrial Ecology, 26(6), 1847–1857. https://doi.org/10.1111/jiec.13156

Richardson K, Hardesty BD, Vince J, Wilcox C. Global estimates of fishing gear lost to the ocean each year. Sci Adv. 2022 Oct 14;8(41). https://doi.org/10.1126/sciadv.abq0135

Maggie Skirtun, Matthias Sandra, Wouter Jan Strietman, Sander W.K. van den Burg, Fien De Raedemaecker, Lisa I. Devriese, Plastic pollution pathways from marine aquaculture practices and potential solutions for the North-East Atlantic region, Marine Pollution Bulletin, Volume 174, 2022,113178, ISSN 0025-326X, https://doi.org/10.1016/j.marpolbul.2021.113178

Toyoshima, J. (2021). *Marine pollution by lost, abandoned and discarded fishing gear*. The Ocean Policy Research Institute, The Sasakawa Peace Foundation. https://www.spf.org/opri/en/global-data/opri/perspectives/prsp_020_2021_toyoshima_en.pdf

A1.3 Diffuse pollution sources

A1.3.1 Artificial turf

Context

In recent years, the use of artificial turfs or recycled rubber mulch (e.g., in playgrounds) has become relatively common. Such a rubber mulch is an obvious source of microplastics (Müller et al., 2020). Plastics used in artificial turf fields tend to degrade over time due to use, UV exposure and weather, releasing microplastics that can spread through runoff, wind, abrasion, and soil infiltration. In addition to this, plastic leakages can also occur through direct mechanical displacement of infill materials, through wind and runoff or due to maintenance activities. Nonetheless, a recent study suggests that besides leading to plastic leakage, infill materials can also just become denser (more compacted) in the own site or even be collected for reuse in the same field. Hence our equation considers plastic leakages due to wearing and to direct losses of infill materials,

concerning the areas with synthetic turf field in certain territory. The proposed equation is aimed to be mainly applied to sport/play fields.

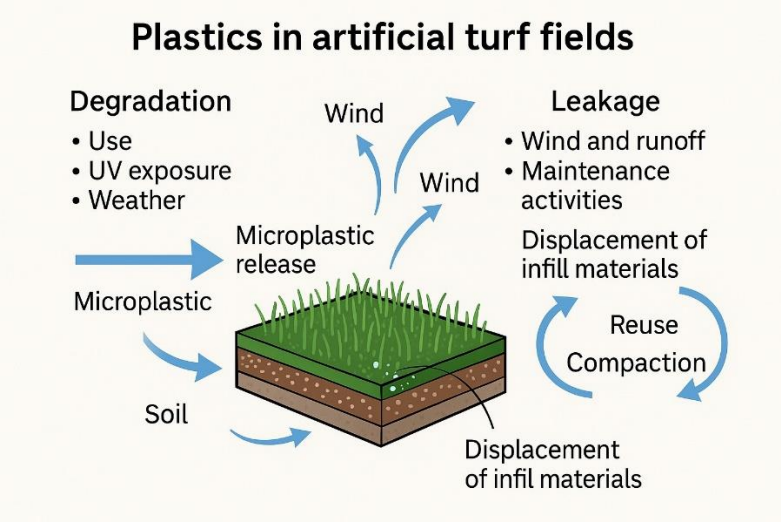


Figure 15. Degradation and leakage of plastics used in artificial turf fields. AI-generated.

Proposed equation

Annual Plastic leakage artificial turf = field area x plastic density x leakage factor +Field Area x infill material loss

$$PL_{turfs} = (FA \times FD \times LF) + (FA \times IL)$$

Where:

- PL $_{turfs}$: Annual plastic leakage from artificial turf covered areas (kg/year)
- FA: Total surface area with synthetic turf fields (m² or ha)
- FD: Weight of synthetic grass fibers per square meter (kg/m²)
- LF: Proportion of fiber mass lost to the environment annually due to wear, degradation, maintenance (%)
- IL: Average mass of infill material lost per square meter each year (e.g., rubber granules, plastic beads)[35] (kg/m²/year)

Reference values

Field areas: Input data.

[35] The infill loss rate may consider an average value of composition of 43% of synthetic Rubber (SBR).

For countries not having granular information about field areas covered by artificial turf, an estimation based on the number of fields can be applied, using average field sizes as a reference (Table 15)

Table 16. Average size of artificial turf fields

Case	Average field size	Source
Typical 11-a-side football	6,400 m²	(Bø et al., 2024)
FIFA standard full-size pitch (106x71m)	7,526 m²	FIFA
Artificial turf field size in Sweden (74×111m)	8,214 m²	(Säberg, 2021)

Fiber Density: Filled turfs typically have face weights of 1,300–1,700 g/m². [36]

Leakage factor (fibers):

Table 17. Plastic leakage factors in turf fields (fibers)

Case	Comment	Source
0.5–0.8 % per year	(assuming ~0.32 mm fiber length loss annually)	FIDRA
5–10 % per year		Lassen et al. 2015
10 % per year		Sundt et al. 2016

Infill loss (Rubber): reported microplastic losses in literature vary widely, ranging from 0.0001 to 5 tons per field per year, depending on the turf and country (Bø et al., 2024). We suggest 40.5 kg/field/year as a safe proxy (Sundan et al., 2025), consistent with other studies (Bø et al., 2020).[37]

Sources

Bø, S. M., Bohne, R. A., Aas, B., & Hansen, L. M. (2020, November). Material flow analysis for Norway's artificial turfs. In *IOP Conference Series: Earth and Environmental Science* (Vol. 588, No. 4, p. 042068). IOP Publishing. https://doi.org/10.1088/1755-1315/588/4/042068

William P. de Haan, Rocío Quintana, César Vilas, Andrés Cózar, Miquel Canals, Oriol Uviedo, Anna Sanchez-Vidal, The dark side of artificial greening: Plastic turfs as widespread pollutants of aquatic environments, Environmental Pollution, Volume 334, 2023,122094,ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2023.122094

Fidra. (n.d.). *Microplastic loss from artificial 3G pitches* (Version 4). https://www.fidra.org.uk/wp-content/uploads/Fidra-Microplastic-loss-from-artificial-3G-pitches_v4-.pdf

[36] https://www.sportslabs.com/field-notes/another-look-at-non-filled-artificial-turf

[37] https://www.genan.eu/wp-content/uploads/2020/02/Teknologisk-Institut_Mass-balance-of-rubber-granulate-lost-from-artificial-turf-fields_May-2019_v1.pdf

Grynkiewicz-Bylina, B., Rakwic, B. & Słomka-Słupik, B. Tests of rubber granules used as artificial turf for football fields in terms of toxicity to human health and the environment. *Sci Rep* 12, 6683 (2022). https://doi.org/10.1038/s41598-022-10691-1

Harusato, A., & Kato, M. (2025). Mechanisms of Generation and Ecological Impacts of Nano- and Microplastics from Artificial Turf Systems in Sports Facilities. *Environments*, *12*(4), 109. https://doi.org/10.3390/environments12040109

Lassen, C., Hansen, S. F., Magnusson, K., Hartmann, N. B., Rehne Jensen, P., Nielsen, T. G., & Brinch, A. (2015). Microplastics: Occurrence, effects and sources of releases to the environment in Denmark. Danish Environmental Protection Agency. https://backend.orbit.dtu.dk/ws/portalfiles/portal/118180844/Lassen_et_al._2015.pdf

Alexandra Müller, Heléne Österlund, Jiri Marsalek, Maria Viklander, The pollution conveyed by urban runoff: A review of sources, Science of The Total Environment, Volume 709, 2020, 136125, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2019.136125

Ryan-Ndegwa S, Zamani R, Martins T. Exploring the Human Health Impact of Artificial Turf Worldwide: A Systematic Review. Environ Health Insights. 2024 Dec 17;18:11786302241306291. https://doi.org/10.1177/11786302241306291 .

Li, R. (2019). *Tracking microplastics from artificial football fields to stormwater systems* (Master's thesis, Stockholm University). Stockholm University, Department of Physical Geography https://www.diva-portal.org/smash/get/diva2:1330304/FULLTEXT02.pdf

OSPAR Commission. (2024). *OSPAR background document on reducing microplastic contamination from performance infill in artificial grass pitches* (Publication No. 1062). Retrieved from https://www.ospar.org/documents?v=57742

Teknologisk Institut. (2019). *Mass balance of rubber granulate lost from artificial turf fields* (Version 1, May 2019). Genan. https://www.genan.eu/wp-content/uploads/2020/02/Teknologisk-Institut_Mass-balance-of-rubber-granulate-lost-from-artificial-turf-fields_May-2019_v1.pdf

A1.3.2 Open burning

Context

Open burning refers to waste that is combusted without leakage cleaning and usually begins with the non-collection of general waste, which was dumped or burned (Figure 16).[38] This section covers plastic leakages from the combustion of plastic waste, which is believed to be the predominant source of plastic leakage across many regions in the world (Cottom et al., 2024b). Demographic and waste management factors will be use to estimate the annual quantity of plastic leakage derived from these conditions, under a comprehensive approach trying to capture all plastic burning by a certain population.

Figure 16. Open burning of littered plastic waste

Source: https://africanclimatereporter.com/2018/06/28/health-implication-of-burning-plastic-in-our-ghettos-community-and-how-it-affect-humananimals/#google_vignette

Proposed equation

Annual Plastic leakage open burning = population x Plastic Waste Generation x per capita leakage factor, or

$$PL \text{ ob} = (\text{Pop} \times \text{PWG}) \text{ LF/cap}$$

[38] https://wedocs.unep.org/bitstream/handle/20.500.11822/44939/global_waste_management_outlook_2024.pdf?sequence=3

Where:

- *PL $_{ob}$*: annual quantity of plastic burned in open conditions (kg)
- *Pop*: Population
- *PWG*: estimated plastic waste generated, kg/per capita/day
- *LF/cap*: average amount of plastic burned openly per person per year (kg/person/year)

Reference values

Population: input data

Plastic waste generation

Table 18. Estimates of plastic waste generation, by country income level

Income classification	Plastic waste generation (kg/per capita/day)
High Income	0.17
UMCs	0.10
LMCs	0.07
LICs	0.04

Source: https://www.nature.com/articles/s41586-024-07758-6

Leakage factor

Table 19. Estimated leakage factors from open burning of plastics, by country income level

Income category (World Bank)	Per capita leakage (kg/person/year)
Low-Income Countries (LIC)	~0.10–0.15 kg/person/year
Lower-Middle Income (LMC)	~0.20–0.30 kg/person/year
Upper-Middle Income (UMC)	~0.35–0.40 kg/person/year
High-Income Countries (HIC)	~0.03–0.07 kg/person/year

Source: https://www.nature.com/articles/s41586-024-07758-6

Sources

Cottom, J.W., Cook, E. & Velis, C.A. A local-to-global emissions inventory of macroplastic pollution. *Nature* **633**, 101–108 (2024). https://doi.org/10.1038/s41586-024-07758-6 [39]

Velis, Costas & Cook, Ed. (2021). Mismanagement of Plastic Waste through Open Burning with Emphasis on the Global South: A Systematic Review of Risks to Occupational and Public Health. Environmental Science & Technology. 55. https://doi.org/10.1021/acs.est.0c08536 .

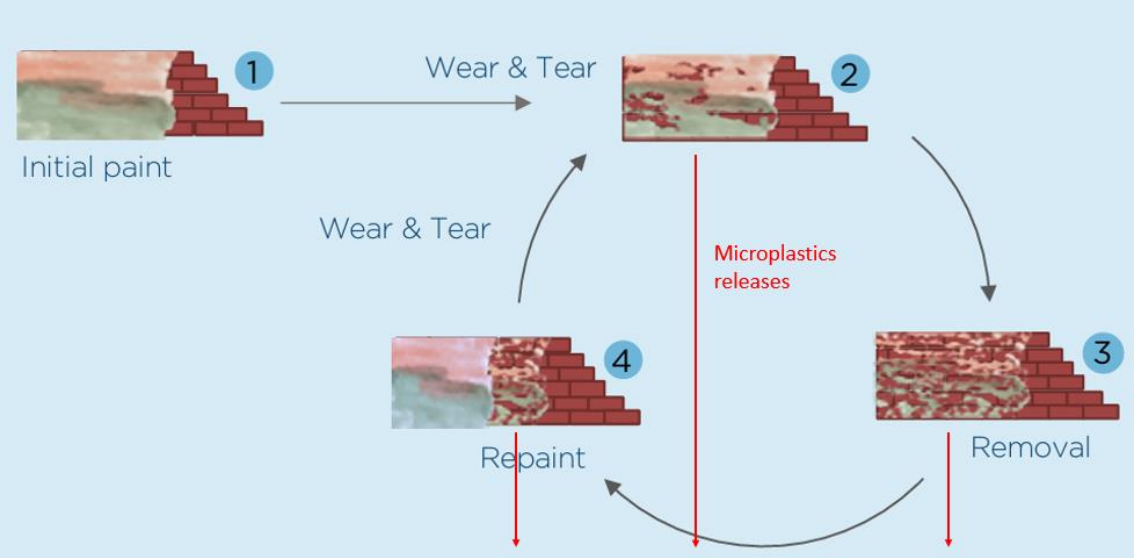
Gauri Pathak, Mark Nichter, Anita Hardon, Eileen Moyer, Aarti Latkar, Joseph Simbaya, Diana Pakasi, Efenita Taqueban, Jessica Love, Plastic pollution and the open burning of plastic wastes, Global Environmental Change, Volume 80, 2023,102648, ISSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2023.102648

Ministry of Environment of Sri Lanka (2024). National Plastic Waste Inventory for Sri Lanka: A Material Flow Approach, "Sobadam Piyasa", Robert Gunawardana Mawatha, Battaramulla, Sri Lanka
env.gov.lk/web/images/pdf/divisions/PollutionControl/Publications/National_plastic_waste_inventory_for_Sri_Lanka_-_MFA_FEB_2024_Final_0509.pdf

A1.3.3 Paints (architectural, roads, and maritime sector)

Context

Paint inks present on average 37% of plastic content, either as primary or secondary microplastics, and can be found on a wide range of objects and infrastructures in our society: cars, boats, indoor walls, buildings and bridges, among others. These plastic leakages are mainly driven by microplastic releases due to UV degradation and mechanical wearing, where paint leak into the ground and eventually escape into nature (Figure 17). We selected three main sectors these phenomena under three main sectors representing most of paints used nowadays: architectural surfaces, road markings and maritime sector.



Source: https://www.e-a.earth/wp-content/uploads/2023/07/plastic-paint-the-environment.pdf (adapted)

Figure 17. Wear and tear of plastics and leakage pathways of microplastics

Plastic leakage from **architectural paints** refers to the release of microplastics and synthetic polymer particles into the environment as painted surfaces on buildings, infrastructure and urban furniture degrade. This leakage is mainly driven by weathering processes such as UV radiation, rain, and temperature fluctuations, as well as physical abrasion and poor maintenance, which cause the gradual breakdown and detachment of polymer-based paint films.

In the case of **road markings**, the release of microplastics and synthetic polymer fragments occur due to degradation over time, primarily due to mechanical abrasion from vehicle tyres, weathering from UV radiation and rain. The proposed equation aims to cover all road markings in a certain territory in a given period, as long as granular data is available.

In the **maritime sector**, paints with certain concentrations of synthetic polymers are used as antifouling paints and marine coatings, and plastic leakage is primarily driven by weathering, mechanical abrasion and leaching of those synthetic polymers and additives. As a result, up to 10% of plastics used in marine coatings are expected to be lost directly into the environment over the lifespan of the product.[40] All maritime vessels in certain space can be covered under the equation, as long as data availability permits so.

For the three subcategories, the total amount of painted surfaces in combination with plastic content and leakage factors may be used as central parameter for the equation.

[40] http://dx.doi.org/10.2305/IUCN.CH.2017.01.en

Proposed equation

Plastic leakage paints = Painted area × paint application rate × plastic content × leakage factor, or

$$PL_{paints} \text{ (Arch, roads, maritime)} = PA \times AR \times PC \times LF$$

Where:

- PL_{paints}: Annual plastic leakage from paints used in architectural surfaces, road markings and maritime sector (kg or Tn)
- PA: Painted area (m²)
- AR: Paint application rate (kg/m²)
- PC: Plastic content in paint (%)
- LF: Leakage factor

Reference values

Painted area: input data.

Application rate and plastic content rate

Table 20. Application rate and plastic content rate

Application	Plastic content rate	Application rate	Leakage factors
Road markings	0.37 (default)[41]	0.4 – 0.8 kg/m² ([42])	0.74[43]
Maritime		0.2–0.3 kg/m² ([44])	0.66[45]
Architectural		0.150–0.250 kg/m² ([46])	Interior walls: 0.23[47]
			Exterior concrete: 0.46[48]
			Exterior wood: 0.71[49]

Complementary values (to be discussed by WG)

[41] https://www.e-a.earth/wp-content/uploads/2023/07/plastic-paint-the-environment.pdf
[42] https://www.dot.ny.gov/divisions/engineering/technical-services/materials-bureau-repository/mp01-02.pdf
[43] https://www.e-a.earth/wp-content/uploads/2023/07/plastic-paint-the-environment.pdf
[44] Sinochem. (2020). Marine Coatings
[45] https://www.e-a.earth/wp-content/uploads/2023/07/plastic-paint-the-environment.pdf
[46] European Commission, Joint Research Centre. (2024). *Draft Technical Report 3: Revision of the EU Ecolabel criteria for Indoor and Outdoor Paints* (3rd consultation). European Union
[47] https://www.e-a.earth/wp-content/uploads/2023/07/plastic-paint-the-environment.pdf
[48] https://www.e-a.earth/wp-content/uploads/2023/07/plastic-paint-the-environment.pdf
[49] https://www.e-a.earth/wp-content/uploads/2023/07/plastic-paint-the-environment.pdf

Table 21. Complementary values (to be discussed by WG)

Application	Sub Activity	Leakage Factor
Road Marking		Optimistic: 23% Central: 43% Pessimistic: 100%[50]
Maritime	Commercial boats	Optimistic/central/pessimistic rates = 3% / 6% / 9%[51]
	Leisure boats (developed economies)	10% / 30% / 50% loss rates[52]
	Leisure boats (developing economies):	50% / 90% loss rates[53]

Sources

Boucher, J. and Friot D. (2017). Primary Microplastics in the Oceans: A Global Evaluation of Sources. Gland, Switzerland: IUCN. 43pp http://dx.doi.org/10.2305/IUCN.CH.2017.01.en

Environmental Action. Retrieved from https://www.e-a.earth/wp-content/uploads/2023/07/plastic-paint-the-environment.pdf

European Commission, Joint Research Centre. (2024). *Draft Technical Report 3: Revision of the EU Ecolabel criteria for Indoor and Outdoor Paints* (3rd consultation). European Union https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2025-02/Draft%20Technical%20Report%203%20EU%20Ecolabel%20paints_for%203rd%20consultation.pdf

Fang, C., Zhou, W., Hu, J. *et al.* Paint has the potential to release microplastics, nanoplastics, inorganic nanoparticles, and hybrid materials. *Environ Sci Eur* 36, 17 (2024). https://doi.org/10.1186/s12302-024-00844-6

International Maritime Organization. (2019). *Hull scrapings and marine coatings as a source of microplastics*. London, UK: International Maritime Organization https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Hull%20Scrapings%20final%20report.pdf

[50] http://dx.doi.org/10.2305/IUCN.CH.2017.01.en
[51] https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf
[52] https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf
[53] https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

Christine C. Gaylarde, José Antonio Baptista Neto, Estefan Monteiro da Fonseca, Paint fragments as polluting microplastics: A brief review, Marine Pollution Bulletin, Volume 162, 2021, 111847, ISSN 0025-326X, https://doi.org/10.1016/j.marpolbul.2020.111847

Tamburri Mario N. , Soon Zhi Yang , Scianni Christopher , Øpstad Christer L. , Oxtoby Neil S. , Doran Simon , Drake Lisa A., Understanding the potential release of microplastics from coatings used on commercial ships, Frontiers in Marine Science, Volume 9,2022, https://doi.org/10.3389/fmars.2022.1074654

Ljungkvist, H., & Aronsson, K. (2023). *Emissions of microplastics to water and air from buildings and construction* (IVL Report No. C695). IVL Swedish Environmental Research Institute. https://www.diva-portal.org/smash/get/diva2:1811470/FULLTEXT01.pdf .

New York State Department of Transportation. (2001). *Pavement marking material guidelines (MP 01-02)*. Materials Bureau. https://www.dot.ny.gov/divisions/engineering/technical-services/materials-bureau-repository/mp01-02.pdf

Andrew Turner, Paint particles in the marine environment: An overlooked component of microplastics,Water Research X,12, 2021, 100110, ISSN 2589-9147, https://doi.org/10.1016/j.wroa.2021.100110

OECD (2022), Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options, OECD Publishing, Paris, https://doi.org/10.1787/de747aef-en.

Paruta, P., Pucino, M., & Boucher, J. (2022). *Plastic paints the environment: A global assessment of paint's contribution to plastic leakage to land, ocean & waterways*. EA –

Sinochem. (2020). Marine Coatings – Theoretical Coverage: 240 g/m² per pass *https://www.sinochem.com/Portals/0/Uploads/Images/ProductZhInt/202012/356b9f95-cb29-454e-b05f-be8236ea1d53.pdf*

Zoie T Diana, Yuying Chen, Chelsea M Rochman, Paint: a ubiquitous yet disregarded piece of the microplastics puzzle, *Environmental Toxicology and Chemistry*, Volume 44, Issue 1, January 2025, Pages 26–44, https://doi.org/10.1093/etojnl/vgae034

United Nations Environment Programme (2018). Mapping of global plastics value chain and plastics losses to the environment (with a particular focus on marine environment). Ryberg, M., Laurent, A., Hauschild, M. United Nations Environment Programme. Nairobi, Kenya.https://wedocs.unep.org/handle/20.500.11822/26745;jsessionid=007D06BBB170D2E506B88D866A267B87

A1.3.4 Shoe soles

Context

Shoe soles, predominantly made from synthetic rubbers and plastics generate microplastics through abrasion during everyday use, where tiny fragments are generated at each step, due to friction with pavement, soil, indoor floors, etc. These minuscule particles, often in the micrometer range may leak into the environment, either through stormwater runoff, as airborne particles or as part of urban dust. This equation aims to consider all people within the target demographic group, taking into consideration their footwear and average walking/running distances.

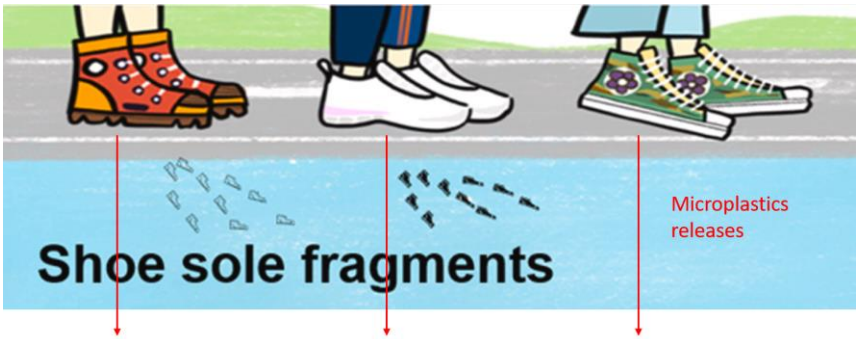


Figure 18. Show sole microplastic releases. Source: Extracted from Kim et al., (2022)

Proposed equation

Plastic leakage shoe soles = Population x leakage factor

$$PL_{shoe} = P \times LF$$

Where:

- PL_{shoe}: Annual plastic leakage from shoe soles (kg)
- P: population
- LF: leakage factor from shoe sole abrasion (kg/person/year)

Reference values

Population: input data

Leakage factor: Several studies propose different values:

- USA: 1.4-40.0 grams of microplastic generated/person/year[54]

[54] The Future Footwear Project

- Denmark: 17-175 grams of microplastic generated/person/year[55][56]
- Germany: 109.1 grams of microplastic generated/person/year[57]

A mean value from the above would be 75.3 grams of microplastic generated per person per year.

Sources

Cecchi, P. (2023). *Plastics on the rocks: The invisible but harmful footprint of shoe soles*. Comptes Rendus. Géoscience, 355, 135–144. https://doi.org/10.5802/crgeos.199

Nicola A. Forster, Susan C. Wilson, Matthew K. Tighe, Trail running events contribute microplastic pollution to conservation and wilderness areas, Journal of Environmental Management, Volume 331, 2023, 117304, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2023.117304

Lassen, C., Hansen, S. F., Magnusson, K., Hartmann, N. B., Rehne Jensen, P., Nielsen, T. G., & Brinch, A. (2015). Microplastics: Occurrence, effects and sources of releases to the environment in Denmark. Danish Environmental Protection Agency. http://mst.dk/service/publikationer/publikationsarkiv/2015/nov/rapport-ommikroplast

Li, K., Yu, K., Zhang, Y. *et al.* Unveiling the mechanism secret of abrasion emissions of particulate matter and microplastics. *Sci Rep* 14, 23710 (2024). https://doi.org/10.1038/s41598-024-74137-6

Lia Kim, Dokyung Kim, Sang A Kim, Haemi Kim, Tae-Yang Lee, Youn-Joo An, Are your shoes safe for the environment? – Toxicity screening of leachates from microplastic fragments of shoe soles using freshwater organisms, Journal of Hazardous Materials, Volume 421, 2022, 126779, ISSN 0304-3894, https://doi.org/10.1016/j.jhazmat.2021.126779

Quantifying and Managing Microplastics From Footwear Use: Outsole Loss Through Wear, Research Project, Andrea Cheung , James Fuller , Teresa Fukuda , Andrew Paterson , Tyanna Bui, Bren School of Environmental Science & Management at UC Santa Barbara 2020, https://bren.ucsb.edu/sites/default/files/2020-10/FutureFootwearBrief.pdf

[55] https://bren.ucsb.edu/sites/default/files/2020-10/FutureFootwearBrief.pdf
[56] http://mst.dk/service/publikationer/publikationsarkiv/2015/nov/rapport-ommikroplast
[57] https://horizon.documentation.ird.fr/exl-doc/pleins_textes/2023-04/010087473.pdf

A1.3.5 Tyre abrasion

Context

Tyre wear particles (TWPs), generated by the friction between tyres and road surfaces, are a major source of microplastic pollution (Figure 19) and are typically composed of both synthetic and natural rubber, along with other additives. Importantly, when tyres wear down, the resulting particles are not purely polymer—they are mixed with mineral particles from the pavement, forming tyre and road wear particles (TRWP), typically in a 50:50 ratio. For plastic leakage assessments, only the polymeric (rubber) fraction of the TRWP should be included, while the mineral road component is excluded.[58]

The determination of such plastic leakages relies on understanding factors such as the type of vehicle, tyre composition (in terms of the proportion of synthetic plastics or natural varieties) and distance traveled by the fleet. Our boundaries here will be set from the moment plastic particles leave the tyres of a fleet (first release) until they escape into unmanaged sphere, and will not consider non-plastic road materials, for a more precise estimation. Given the complexity of the transfer coefficients of TWP y(it can go directly into nearby soil, into the air, into waterways, or be retained in the asphalt), we assume that all mass loss of polymers goes to the environment.

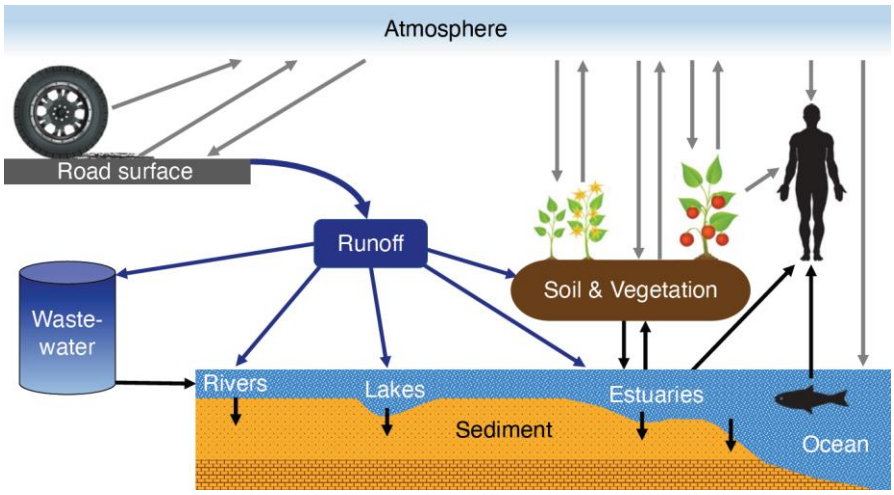


Figure 19. *Tyre-wear plastic particles: runoff, leakage pathway and transport to various environmental compartments. Source: UNEP, (2024)*

[58] https://quantis.com/report/the-plastic-leak-project-guidelines/

Proposed equation

Plastic leakage tyres = travelled distance by tyres x plastic fraction x leakage factor

$$PL_{\text{tyres}} = D \times FP \times LF$$

Where:

- PL_{tyres}: annual plastic leakage from tyres (kg)
- D: total distance traveled by the fleet (km)
- FP: fraction of the tyre tread that is made up of plastic polymers
- LF: leakage factor due to tyre tread abrasion (in mg/km)

Reference values

Distance: input data.

Plastic fraction and Leakage factors

Table 22. Loss of tyre tread in mg per kilometer travelled by the vehicle and share of polymer in the tread (Median values from PLP)

Type of Vehicle	Loss of tyre tread in mg per kilometer travelled by the vehicle	Share of polymer fraction in the tread (to be used as fraction of plastic) %
Motorcycle	45	40
Scooter	45	50
Passenger Car	102	35
Light Truck	142	36
City Bus	415	50
Long Haul Coach	325	58
Medium/Heavy Truck Long Haul	517	60
Medium/Heavy Truck Short Haul	658	50

Source: PLP https://quantis.com/report/the-plastic-leak-project-guidelines/

Complementary values (to be discussed by WG)

Table 23. Default tread mass loss values by vehicle type, expressed in mg of tread loss per kilometer traveled (mg tread/km)

Type of vehicle	$Loss_{vehicle_tyres}$ **Loss of tire tread, in mg per kilometer travelled by the vehicle** [mg (tread) / (vhc*km)]

		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[59]	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

Table 24. Share of polymer (synthetic rubber + natural rubber) in tire tread for different types of vehicles

Type of vehicle		$ShPolymer_{vehicle_tyre}$ **Share of polymer fraction (synthetic rubber + natural rubber) in tire tread** [kg (microplastics[60]) / 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

[59] 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.

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

	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

Source: PLP

Sources

Laura Peano et al, Plastic Leakage Project, Quantis & EA, 2020. https://quantis.com/report/the-plastic-leak-project-guidelines/

Giechaskiel, B., Grigoratos, T., Mathissen, M., Quik, J., Tromp, P., Gustafsson, M., Franco, V., & Dilara, P. (2024). Contribution of Road Vehicle Tyre Wear to Microplastics and Ambient Air Pollution. *Sustainability*, *16*(2), 522. https://doi.org/10.3390/su16020522

Jung, U., & Choi, S.-S. (2022). Classification and Characterization of Tyre-Road Wear Particles in Road Dust by Density. *Polymers*, *14*(5), 1005. https://doi.org/10.3390/polym14051005

MASTER OF SCIENCE THESIS COMPOUNDING AND CHARACTERIZATION OF TYRE TREAD COMPOUNDS USING FUNCTIONALIZED RUBBER SIMON REZELMAN S1721542 MSC. MECHANICAL ENGINEERING, https://essay.utwente.nl/96281/1/Rezelman_MA_ET.pdf

Michael Kovochich, Monty Liong, Jillian A. Parker, Su Cheun Oh, Jessica P. Lee, Luan Xi, Marisa L. Kreider, Kenneth M. Unice, Chemical mapping of tyre and road wear particles for single particle analysis, Science of The Total Environment, Volume 757, 2021, 144085, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.144085

Mattsson, K., de Lima, J.A., Wilkinson, T. *et al.* Tyre and road wear particles from source to sea. *Micropl.&Nanopl.* **3**, 14 (2023). https://doi.org/10.1186/s43591-023-00060-8

Luiza Ostini Goehler, Rodrigo Braga Moruzzi, Fabiano Tomazini da Conceição, Antônio Aparecido Couto Júnior, Lais Galileu Speranza, Rosa Busquets, Luiza Cintra Campos, Relevance of tyre wear particles to the total content of microplastics transported by runoff in a high-imperviousness and intense vehicle traffic urban area., Environmental

Pollution, Volume 314, 2022, 120200, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2022.120200

Julie M. Panko, Jennifer Chu, Marisa L. Kreider, Ken M. Unice, Measurement of airborne concentrations of tyre and road wear particles in urban and rural areas of France, Japan, and the United States, Atmospheric Environment, Volume 72, 2013, Pages 192-199, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2013.01.040 .

Stephan Wagner, Thorsten Hüffer, Philipp Klöckner, Maren Wehrhahn, Thilo Hofmann, Thorsten Reemtsma, Tyre wear particles in the aquatic environment - A review on generation, analysis, occurrence, fate and effects, Water Research, Volume 139,2018, Pages 83-100, ISSN 0043-1354, https://doi.org/10.1016/j.watres.2018.03.051

A1.4 Wastewater

Context

Wastewater treatment plants (WWTP) seek to remove microplastics (along with other suspended solids) from sewage, through primary, secondary and tertiary treatment methods (Figure 20), and even though discharged waters should be totally free of contamination, it's reasonable to assume that a complete cleaning would be inconceivable (Sugiura et al., 2021), and these discharged waters will therefore normally present some level of MP contamination.

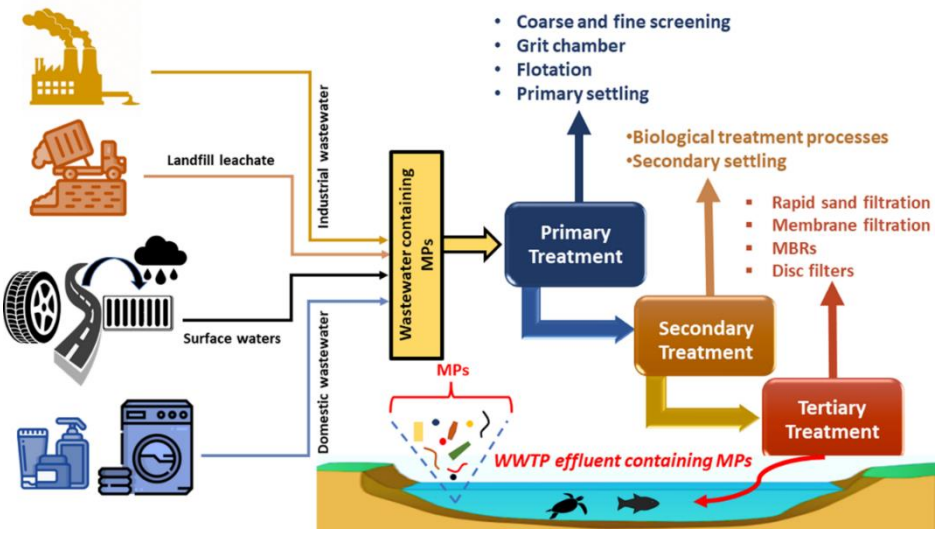


Figure 20. Microplastics sources in wastewater treatment plants and treatment stages. Source: Extracted from Acarer, 2023)

Direct plastic leakage may also occur for wastewater bypassing WWTPs before treatment, as wastewater systems may overflow during storms and floodings (Hitchcock, 2020).

Proposed equation

Plastic leakage wastewater = concentration of microplastics in input wastewater + WWTP's removal efficiency + microplastics in bypass discharges

$$PL\ wwtp = (WWt \times RE) + (WWb \times MC)$$

Where:

- *PL wwtp*: annual plastic leakage from wastewater treatment system (kg)
- *WWt*: Volume of wastewater treated by WWTPs (m^3/day, m^3/year)
- RE: WWTP's microplastics removal efficiency
- *WWo*: Volume of wastewater bypassing WWTPs due to overflow (m^3/day, m^3/year)
- *MC*: Microplastics concentration in the treated effluent (mg/m^3)

Reference values

Wastewater treated: input data

Removal efficiency and microplastic concentration in effluents

Table 25. Removal efficiency and microplastic concentration in effluents

Treatment Stage	Removal Efficiency for MPs (Ranges from existing literature)	Microplastics concentration in treated effluent	Notes and sources
No treatment Untreated sewage.	0%	1–10 mg/L	Raw wastewater may contain ~2.5–13.6 mg/L of MPs https://doi.org/10.3390/microplastics3020017
Primary Screens & sedimentation	~50–80%	~0.5–5 mg/L	https://doi.org/10.3390/toxics12010012
Secondary Bioreactor & clarifier	~85–95%	~0.05–0.5 mg/L	https://doi.org/10.3390/toxics12010012 and https://doi.org/10.1016/j.watres.2018.12.050
Advanced/Tertiary Filtration, membrane (Depending on type of tertiary treatment)	95% - 99,9%	~0.05 - 0.000067 mg/L	https://doi.org/10.1039/D0EW00397B https://www.sciencedirect.com/science/article/abs/pii/S0043135417305687

Volume of wastewater bypassing

Table 26. Wastewater bypassing estimates

Region / Study	Fraction of Untreated Flow (%)	Notes and sources
USA	3–10% under normal conditions; up to 100% during extreme storms	By-pass due to hydraulic overload; many plants operate with combined sewer systems (CSOs) EPA (2004).
Europe	2%-5%	Council of the EU, Press release, 2024
Latin America	Variable data; local estimates suggest 70%-80% is not treated	Especially in cities with outdated systems, limited coverage, or intense rain events. https://doi.org/10.18235/0006192
Global	~10–30% of wastewater may bypass full secondary treatment	Includes direct discharges due to lack of capacity, poor design, or extreme events. WWAP (2020). UN World Water Development Report. Link

Sources

Ballestero, M., Arroyo, V., & Mejía, A. (2015). *Inseguridad económica del agua en Latinoamérica: De la abundancia a la inseguridad*. CAF – Banco de Desarrollo de América Latina. https://scioteca.caf.com/bitstream/handle/123456789/787/CAF%20Inseguridad%20economica%20del%20agua%20America%20del%20Sur.pdf

Garzón, C., & Sturzenegger, G. (2016). *Los desafíos de la agenda de desarrollo post-2015 para el sector de agua y saneamiento en América Latina y el Caribe: Conclusiones de la Semana Mundial del Agua 2015*. Banco Interamericano de Desarrollo. https://doi.org/10.18235/0006192

Bayo, J., López-Castellanos, J., & Olmos, S. (2020). Microplastics in an urban wastewater treatment plant: The influence of physicochemical parameters and sludge retention time. Journal of Environmental Management, 255, 109739. https://doi.org/10.1016/j.jenvman.2019.109739

Cheng, Y., Wang, J., Li, Y., Li, Y., & Wang, Y. (2023). Microplastics in wastewater treatment plants: Sources, properties, and removal. *Water Science & Technology*, 87(3), 685–700. https://doi.org/10.2166/wst.2023.036

Lares, M., Ncibi, M. C., Sillanpää, M., & Sillanpää, M. (2018). Intercomparison study on commonly used methods to determine microplastics in wastewater and sludge samples. *Environmental Science and Pollution Research*, 25(4), 3443–3453. https://doi.org/10.1007/s11356-017-0740-7

Lau, P., Stein, J., Reinhold, L., Barjenbruch, M., Fuhrmann, T., Urban, I., Bauerfeld, K., & Holte, A. (2024). Reduction in the Input of Microplastics into the Aquatic Environment via Wastewater Treatment Plants in Germany. *Microplastics*, *3*(2), 276-292. https://doi.org/10.3390/microplastics3020017

Lv, X., Dong, Q., Lo, I. M. C., & Li, H. (2023). The impact of extreme precipitation on microplastic removal in wastewater treatment plants. *Journal of Hazardous Materials*, 448, 130956. https://doi.org/10.1016/j.jhazmat.2023.130956

Xuemin Lv, Qian Dong, Zhiqiang Zuo, Yanchen Liu, Xia Huang, Wei-Min Wu, Microplastics in a municipal wastewater treatment plant: Fate, dynamic distribution, removal efficiencies, and control strategies, Journal of Cleaner Production, Volume 225, 2019, Pages 579-586, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2019.03.321 .

Masaya SUGIURA, Hideshige TAKADA, Naohiko TAKADA, Kaoruko MIZUKAWA, Shumpei TSUYUKI, Hiroaki FURUMAI, Microplastics in urban wastewater and estuarine water: Importance of street runoff, Environmental Monitoring and Contaminants Research, 2021, Volume 1, Pages 54-65, Released on J-STAGE April 16, 2021, Online ISSN 2435-7685, https://www.jstage.jst.go.jp/article/emcr/1/0/1_20200006/_article/-char/

Reza, T., Mohamad Riza, Z. H., Sheikh Abdullah, S. R., Abu Hasan, H., Ismail, N. 'I., & Othman, A. R. (2024). Microplastic Removal in Wastewater Treatment Plants (WWTPs) by Natural Coagulation: A Literature Review. *Toxics*, *12*(1), 12. https://doi.org/10.3390/toxics12010012

Phuong Linh Ngo, Biplob Kumar Pramanik, Kalpit Shah, Rajeev Roychand, Pathway, classification and removal efficiency of microplastics in wastewater treatment plants, Environmental Pollution, Volume 255, Part 2, 2019, 113326, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2019.113326

Julia Talvitie, Anna Mikola, Arto Koistinen, Outi Setälä, Solutions to microplastic pollution – Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies, Water Research, Volume 123, 2017, Pages 401-407, ISSN 0043-1354, https://doi.org/10.1016/j.watres.2017.07.005

Rikard Tröger, Philipp Klöckner, Lutz Ahrens, Karin Wiberg, Micropollutants in drinking water from source to tap - Method development and application of a multiresidue screening method, Science of The Total Environment, Volume 627, 2018, Pages 1404-1432, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.01.277

Jing Sun, Xiaohu Dai, Qilin Wang, Mark C.M. van Loosdrecht, Bing-Jie Ni, Microplastics in wastewater treatment plants: Detection, occurrence and removal, Water Research,

Volume 152, 2019, Pages 21-37, ISSN 0043-1354,
https://doi.org/10.1016/j.watres.2018.12.050

A1.5 Solid waste management

Context

The equation for solid waste management is structured around four main categories (Figure 21):

1. Waste collection: refers to gathering waste materials from various sources, such as households, businesses, and public spaces, for the purpose of transport to treatment or disposal facilities;

2. Sorting: involves categorizing plastics using both manual and mechanical methods based on type, volume, and other characteristics;

3. Transportation: moving plastic waste from collection points to treatment facilities or final disposal sites;

4. Disposal/End of Life: The final stage encompasses how plastic waste is managed at the end of its lifecycle for final disposal.

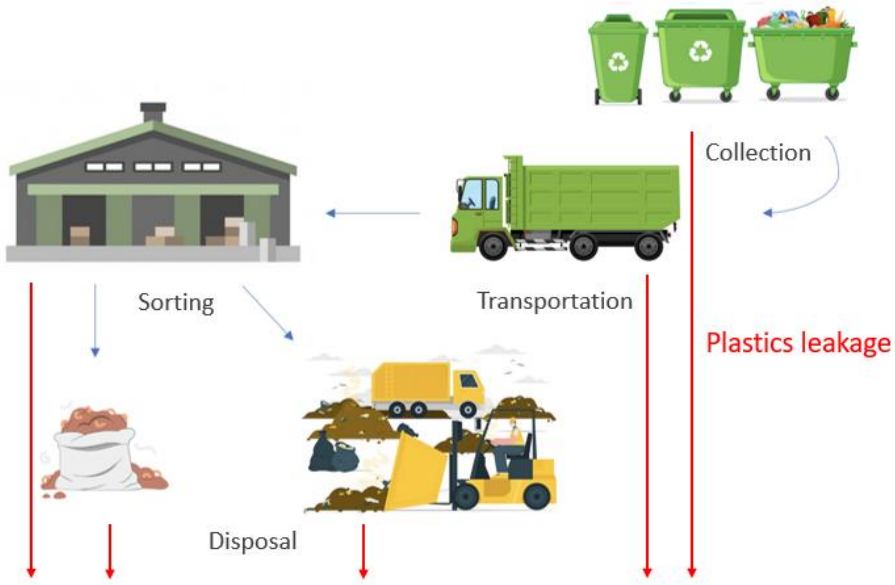


Figure 21. Four typical phases of solid waste management. Source: Extracted from Ahmed Khan et al., (2024)

The proposed equation assumes that plastic leakage in MSW is made up of the total amount of plastics generated as a waste applied to leakage rates across the four stages. In this context, a first set of values is proposed as broad indicator across different countries, taking into account common data limitations.

Proposed equation

Annual Plastic leakage waste management = total plastic waste generated x leakage factors in collection, sorting, transportation and disposal, or

$$PL_{SWM} = PW \times (LFcol + LF_{sort} + LFtransp + LF_{disp})$$

Where:

- PL_{SWM}: Annual plastic leakage during solid waste management activities (kg or Tn)
- PW: Annual plastic waste generated (kg or Tn)
- LF_{col}: Leakage factor during waste collection (%)
- LF_{sort}: Leakage factor during sorting (%)
- LF_{transp}: Leakage factor during transportation (%)
- LF_{disp}: Leakage factor during disposal (%)

Reference values

Plastic waste generated: input data.

If granular data is not available, it can be inferred from plastic proportion within solid waste composition, as per the table below.

Table 27. Waste generation and collection rates and plastic composition, by region, 2020

Region	Waste generation (kg/capita/day)	Collection rate	Plastic in waste composition
Australia and New Zealand	1.46	93%	8 %
Central America and the Caribbean	0.93	83%	11%
Central and South Asia	0.39	37%	5%
East Asia	0.70	75%	12%
East Europe	1.04	96%	12%

Latin America	1.14	65%	10%
North Africa	1.13	51%	9%
North America	2.22	94%	12%
Oceania	0.95	34%	9%
South-East Asia	1.14	49%	13%
Sub-Saharan Africa	0.65	44%	9%
West Asia	1.14	65%	9%
Western Europe	1.46	97%	12%

Source: Global Waste Management Outlook 2024

Leakage factors

Table *28*. Leakage factors for the four stages of solid waste management

Stage	Low (%)	Intermediate (%)	High (%)
Collection	6	22.5	45
Sorting	30	38.75	47.5
Transport	2.5	4.25	6
Final Disposal	5	11.25	17.5

Source: Waste flow Diagram (https://www.giz.de/expertise/html/62153.html)

Sources

Cottom, J.W., Cook, E. & Velis, C.A. A local-to-global emissions inventory of macroplastic pollution. *Nature* **633**, 101–108 (2024). https://doi.org/10.1038/s41586-024-07758-6

Joshua W. Cottom, Ed Cook, Costas A. Velis et al. Plastic pollution emission factors: How much escapes, how far it goes, and how to intervene in the solid waste management system, 12 August 2024, PREPRINT (Version 1) available at Research Square https://doi.org/10.21203/rs.3.rs-4850420/v1

GIZ, University of Leeds, Eawag, & Wasteaware. (2020). Waste Flow Diagram (WFD) Methodology for Assessing Plastic Leakage in Waste Management Systems. Available at: https://wfd.rwm.global

Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. “What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050.” Overview booklet. World Bank, Washington, DC. License: Creative Commons Attribution CC BY 3.0 IGO. https://openknowledge.worldbank.org/server/api/core/bitstreams/92a50475-3878-5984-829e-0a09a6a9badc/content

Ministry of Environment (2024). National Plastic Waste Inventory for Sri Lanka: A Material Flow Approach, “Sobadam Piyasa”, Robert Gunawardana Mawatha, Battaramulla, Sri Lanka
env.gov.lk/web/images/pdf/divisions/PollutionControl/Publications/National_plastic_waste_inventory_for_Sri_Lanka_-_MFA_FEB_2024_Final_0509.pdf

United Nations Environment Programme (2024). Global Waste Management Outlook 2024: Beyond an age of waste – Turning rubbish into a resource. Nairobi.
https://wedocs.unep.org/20.500.11822/44939

A1.6 Plastic recovery

Context

The leakage factor for the recovery sector should consider the three main techniques for plastic recovery: mechanical and chemical recycling and energy recovery; ideally with specific sub-coefficients for each of them. Notwithstanding, chemical recycling is yet a scarce technique (usually less than 1% even in HIC) and we decided to consider only mechanical recycling and energy recovery (Figure 22), by considering volume of plastics recovered vis-à-vis conversion and plastic mismanagement rates. These rates are quite challenging to come up with a single, precise figure, for the complexity of plastic management and recycling (Geyer et al., 2017); hence we acknowledge the estimations suggested here are quite generic, requiring further studies for more precise proxies.

For the case of incineration, even though it is considered to enable the thermal destruction of plastics (converting them into CO2 and mineral fraction) (Yang et al., 2021), microplastics such as fibers may still be detected in the bottom ashes (Chimenos et al., 1999), entailing risks of plastic pollution if not well handled.

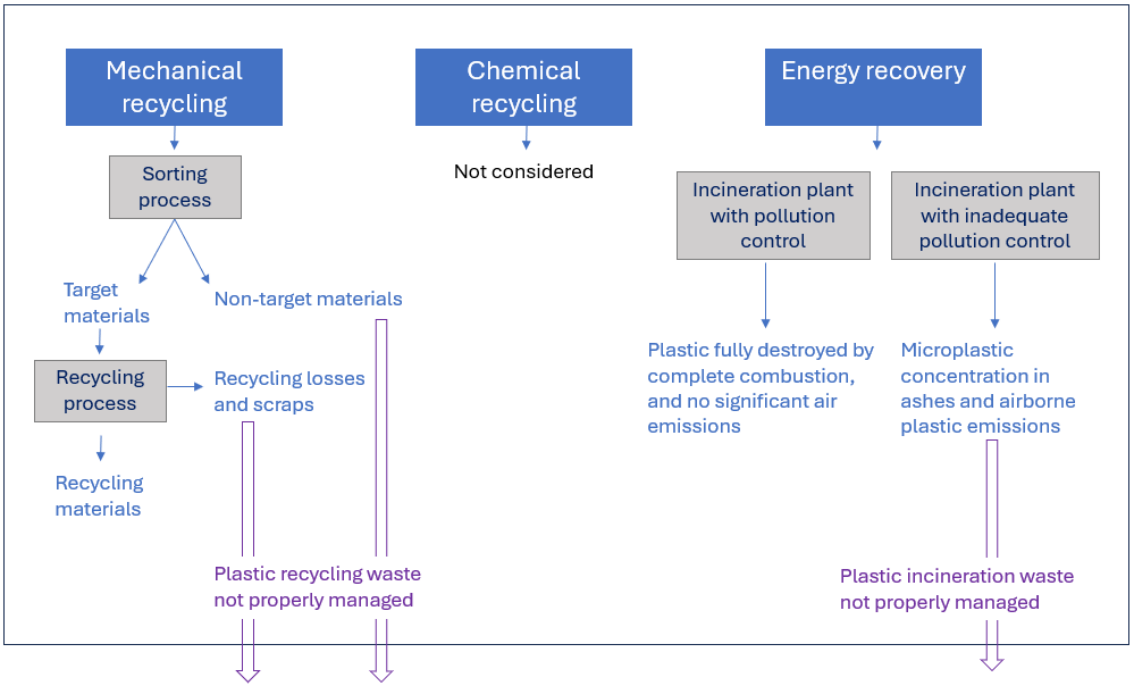


Figure 22. Boundaries and plastic flows for plastic recovery

Proposed equation

Plastic leakage recovery = plastic materials handled x recycling conversion rates and plastic incinerated x leakage factor, applied to plastic mismanagement rates, or

$$PL_{recovery} = PMH - [(PMH \times CR) \times PWM] + [(PI \times LF) \times PWM]$$

Where:

- $PL_{recovery}$: Annual plastic leakage from plastic recovery activities (kg/year)
- *PMH*: plastic waste received by recycling facilities (ton/year)
- *CR*: conversion rates of plastic waste into recycled materials, composed of sorting rates and material substitution factors (%)
- *PWM*: plastic waste mismanagement rate (%)
- *PI*: Plastic incinerated in the target area (kg/year)
- *LF*: leakage factor from plastic incineration in facilities with no adequate pollution control (%)

Reference values

Plastic waste received by recycling facilities: input data.

In case no data is available, an estimation can be derived from the recycled materials effectively processed for the manufacturing of new products, according to the substitution factors between recycled and virgin material (table below).

Sorting rates and substitution factors

Mechanical recycling

Table 29. Sorting rates and substitution factors

Polymer type	Sorting rate	Substitution factor
PET (both amorphous and bottle grade)	91%	0.9 (amorp.); 1 (bot)
HDPE	91%	0.9
LDPE	73%	0.75
PP	79%	0.9
PS	65%	0.9
EPS	65%	0.9
PUR	65%	0.9
PVC	73%	0.9
Default value (for other polymers and mixed, unsorted plastic wastes)	90%	0.9

Source: Tonini, D., Garcia-Gutierrez, P., and Nessi, S., Environmental effects of plastic waste recycling.

Plastic waste mismanagement

Table 30. Plastic waste mismanagement estimates, by country/region

Country/region	Plastic waste mismanaged
Canada	7%
China	27%
India	46%
Latin America	42%
Middle East & North Africa	40%
Non-OECD	39%
OECD	6%
OECD Asia	2%
OECD EU countries	5%
OECD Non-EU countries	8%
OECD Oceania	7%
Other Africa	64%
Other EU	11%
Other Eurasia	40%
Other non-OECD Asia	45%
Other OECD America	20%
USA	4%
World	22%

Source: OECD ENV-Linkages model (https://stat.link/wer8fl).

Plastic incinerated: input data, being necessary identification of burning with no adequate pollution control.

Leakage factor in IP

Leakage coefficients of plastic incineration may depend on incineration plants' emission control technologies as well design and operation features.

Concrete information was found on "microplastics loss on ignition" (LOI)[61] for two furnace types, indicating the presence of microplastics in bottom ash from municipal solid waste incinerators (table 31) (Yang et al., 2021).

Table 31. Furnace type and microplastics loss on ignition

Furnace type	Loss on ignition	
	Range of values found	Mean value
Mass burn furnace	3% -5%	4%
Fluidized bed furnace	2% - 4%	3%

Source: https://www.sciencedirect.com/science/article/pii/S0304389420314187#bib0040

Sources

Roland Geyer et al. Production, use, and fate of all plastics ever made.Sci. Adv.3,e1700782(2017).DOI:10.1126/sciadv.1700782

J.M Chimenos, M Segarra, M.A Fernández, F Espiell, Characterization of the bottom ash in municipal solid waste incinerator, Journal of Hazardous Materials, Volume 64, Issue 3, 1999, Pages 211-222, ISSN 0304-3894, https://doi.org/10.1016/S0304-3894(98)00246-5

Schyns, Z. O. G., & Shaver, M. P. (2021). *Mechanical recycling of packaging plastics: A review*. Macromolecular Rapid Communications, 42(3), e2000415. https://doi.org/10.1002/marc.202000415

Tonini, D., Garcia-Gutierrez, P. and Nessi, S., Environmental effects of plastic waste recycling, EUR 30668 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-41130-7, https://doi.org/10.2760/6309

Zhan Yang, Fan Lü, Hua Zhang, Wei Wang, Liming Shao, Jianfeng Ye, Pinjing He, Is incineration the terminator of plastics and microplastics?, Journal of Hazardous Materials, Volume 401, 2021, 123429, ISSN 0304-3894, https://doi.org/10.1016/j.jhazmat.2020.123429

[61] Loss on ignition (LOI) is used as an indicator of the unburned material in the bottom ash.

Annex 2: Terminology

(to be developed in a further version)

Terms used in this study	Definition	Equivalent terms	Reason for selected terms and definition
Transfer coefficient		Distribution (TNO report), pollution pathways, movement, pollution dynamics, spread (UNSBO)	
End products			
Plastic handling	Encompasses everything? From production to eol and final disposal? {check UNITAR}		
Leakage		Outflow, losses, discharges, emissions, releases	
Managed system		Anthroposphere, technosphere, economic system,	
Plastics			
Plastic material			
Plastic and plastic-containing products			
Recovery		Recycling, reprocessing	

Annex 3: Proposal of leakage factors

Below, a series of methodological proposals for estimating plastic leakage along the value chain are proposed. These characterizations contain a description of the key processes and phenomena in each sector and a proposed methodological approach for estimating plastic leakage into the environment.

Clarification: Contextualization of Reference Values by Country Income Level

In developing the methodological proposals for plastic leakage estimation across the plastic value chain, particular efforts were made to provide default reference values whenever robust and applicable data were available. For certain sectors—such as solid waste management, material recovery, or plastic production—plastic leakage factors could be meaningfully stratified according to the income levels of countries (e.g., Low-Income Countries [LIC], Lower-Middle-Income Countries [LMC], Upper-Middle-Income Countries [UMC], and High-Income Countries [HIC]). This characterization may be possible due to the availability of relevant empirical data and widely recognized differences in infrastructure quality, operational practices, and regulatory frameworks among countries of different income levels.

However, for other source categories, particularly those related to consumption-based activities (e.g., construction, fisheries, agriculture) or diffuse emission phenomena (e.g., tire abrasion, paint, open burning)—such characterization may not be feasible. These activities are highly dependent on local environmental conditions, cultural practices, material choices, and other context-specific variables that cannot be reliably generalized based on income levels alone. In these cases, assigning income-based reference values would introduce greater uncertainty and risk oversimplification.

Therefore, for these sectors, a more flexible approach was taken. Users are encouraged to rely on locally derived data when available or apply case-specific estimates guided by scientific literature and expert judgment, as detailed in the corresponding annex sections. In all cases, transparency in assumptions and consideration of uncertainty ranges remain essential to ensure the coherence and credibility of the resulting estimates.

For most of the sectors considered, equations have been proposed to facilitate the estimation of plastic leakage at each stage of the value chain. As mentioned above, these equations and their components are highly dependent on available activity data. Bringing as an example the solid waste management sector, an explanation about what is understood in terms of equation, reference values and leakage/emission actors is provided below.

Equation:

The proposed **equation** to estimate plastic leakages in the Solid Waste Management (SWM) sector is composed, from a macro perspective, of two main elements: the total volume of plastic generated as waste and the emission factors or Plastic Leakage Factors (PLFs), representing the leakage or loss percentages at each stage of the management process.

Reference value:

In the event that the country or jurisdiction does not have its own activity data, a **reference value** may be provided, A reference value is a parameter obtained from scientific literature, established

methodologies (such as the Waste Flow Diagram—WFD), or internationally recognized specific studies. Its purpose is to provide standard or approximate data in contexts where specific or local information is unavailable or limited.

For example, the values provided in the document present three reference levels for each stage (low, intermediate, and high), simplified from existing methodologies, facilitating their application in different global contexts.

Leakage factor:

The **"leakage factor"** represents the estimated percentage of plastic that escapes or is released into the environment at a specific management stage. This factor is a specific value calculated or selected according to the precision level of available data (low, intermediate, or high) and depends on the quality of the waste management system (formal or informal).

Thus, these emission factors can vary considerably based on:

- The efficiency and formality of the system (formal/informal).
- Operational practices and technological sophistication implemented at each stage (collection, sorting, transportation, and disposal).

For instance, in an efficient formal system, the emission factor in the transportation stage might be as low as 0% (low level) and up to 2% (high level), while in less efficient informal systems, this value could range between 5% and 10%. In summary, the proposed equation combines global information (total generated waste) with specific leakage factors based on reference values from scientific literature, enabling estimations adjusted according to available information levels and the specific characteristics of the system analyzed.