PRE-PRINT: MODULE UNDER SCIENTIFIC COMMITTEE REVEW

Plastic Footprint Network

Plastic Footprint Guidelines

Module on impacts of microplastic leakage

Version 1

Convened by EA – Earth Action · www.plasticfootprint.earth

Leading organizations have united within the Plastic Footprint Network to chart a new, more effective **path toward plastic pollution** mitigation.

The network's first priority was **unifying the framework** for measuring plastic leakage into a **single**, **science-based methodology** for organizations to accurately assess the environmental impact of their plastic use. Over **100 professionals** from **35 organizations** worked to establish the resulting **methodology**, which consists of **11 modules**, all optimized for usability and delivery of **actionable results**.

Objectives

Unifying the methodologies and perspectives of leading scientists, experts, and global practitioners. PFN enables organizations to understand the full impact, or footprint, from the use of plastic in their companies, products, and services.

1. Update and unify plastic footprinting methodologies
2. Ensure the methodology is used consistently by practitioners
3. Disseminate and scale the use of plastic footprinting
4. Explore link with plastic credit schemes, and how to prevent greenwashing claims

What are the objectives of this module

Note : this module is currently under scientific review and may undergo changes through the review process

The aim of this module is to establish a standardized approach for evaluating the potential impacts of microplastic leakage on ecosystem quality, using a life cycle assessment (LCA) approach. To fulfill this goal, we will address the following three key questions:

1. What is the **current understanding and knowledge** regarding the potential impacts of microplastic leakage on ecosystems? Which of these aspects have been integrated into LCA methodologies?

2. What **LCA characterization factors** are essential for accurate calculations, and how can they be integrated into the assessment process?

3. How can an **effective methodology**, drawing from diverse sources including past experiences and literature, be structured and implemented to gauge the potential impacts of microplastic leakage on ecosystem quality, within the context of a plastic footprint?

Before implementing the following impact methodology, users should first calculate their microplastic leakage using the methodologies provided by the Plastic Footprint Network. This value will serve as input to the calculations in this module.

At the end of this module, the users should know how to expand their plastic footprint to consider the potential damage of microplastic leakage on ecosystem quality.

Where does this module fit in the PFN landscape?

Guidance

Strategic | Cross-cutting or specific issue

- Introduction to plastic footprinting
- Scopes and boundaries
  Alignment with environmental reporting standards
- Data governance
- Mitigation framework (new)

Technical

- Technical introduction to plastic leakage
- Glossary

Inventory: Macroplastics

- Packaging
- Textile
- Fishing gears (new)
- Leakage from export (TBD)
- Release rates (TBD)
- Automotive (TBD)
- Construction (TBD)

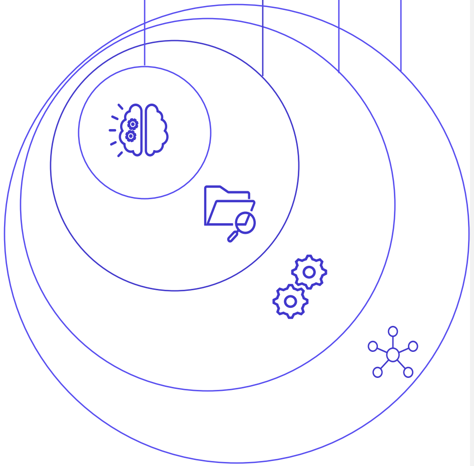
Inventory: Microplastics

- Micro tyre dust
- Micro textile fibres
- Micro agriculture (new)
- Micro paint (TBD)
- Micro pellets (TBD)

Impact

- Impact MariLCA (new) — Current module

Structure of each technical module



1 Methodological choice

High level overview and different methodologies available at the moment and which one(s) to use.

Target audience: busy readers, scientific journalists

2 System map and calculation routes

- The different elements to take into account during an impact assessment.
- How these elements interact.
- The calculation routes to follow.

Target audience: busy readers, scientific journalists

3 Models & background assumptions

The LCA characterization factors needed to perform the assessment and which ones to chose.

Target audience: scientists and LCA practitioners. aiming at performing a plastic footprint

4 Case study

A concrete example illustrating how the methodology can be integrated into an life cycle assessment.

Target audience: LCA practitioners.

5 Outlook

Future prospect and potential integration of macroplastic impacts

Reading keys: Main take away | Supporting information | Key warning

Part. 1

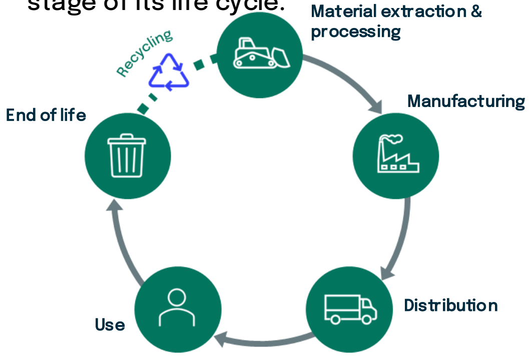
Methodological choice

The different methodologies available at the moment, which one(s) to use and when.

Useful definitions

Life cycle assessment (LCA)

Environmental Life Cycle Assessment (LCA) is a systemic framework that assesses the potential environmental impacts of a product or service at every stage of its life cycle.



Characterization factor (CF)

In the context of LCA, characterization factors are quantitative values used to translate leakage results into an environmental impact through a specific indicator. They represent impact pathways. They allow for the assessment and comparison of different types of emissions and resource uses by expressing their potential impacts on the environment or human health in a standardized way. Essentially, characterization factors help in translating the diverse environmental burdens into comparable units, facilitating the aggregation and interpretation of impact results in the context of LCAs.

Physical effects on biota

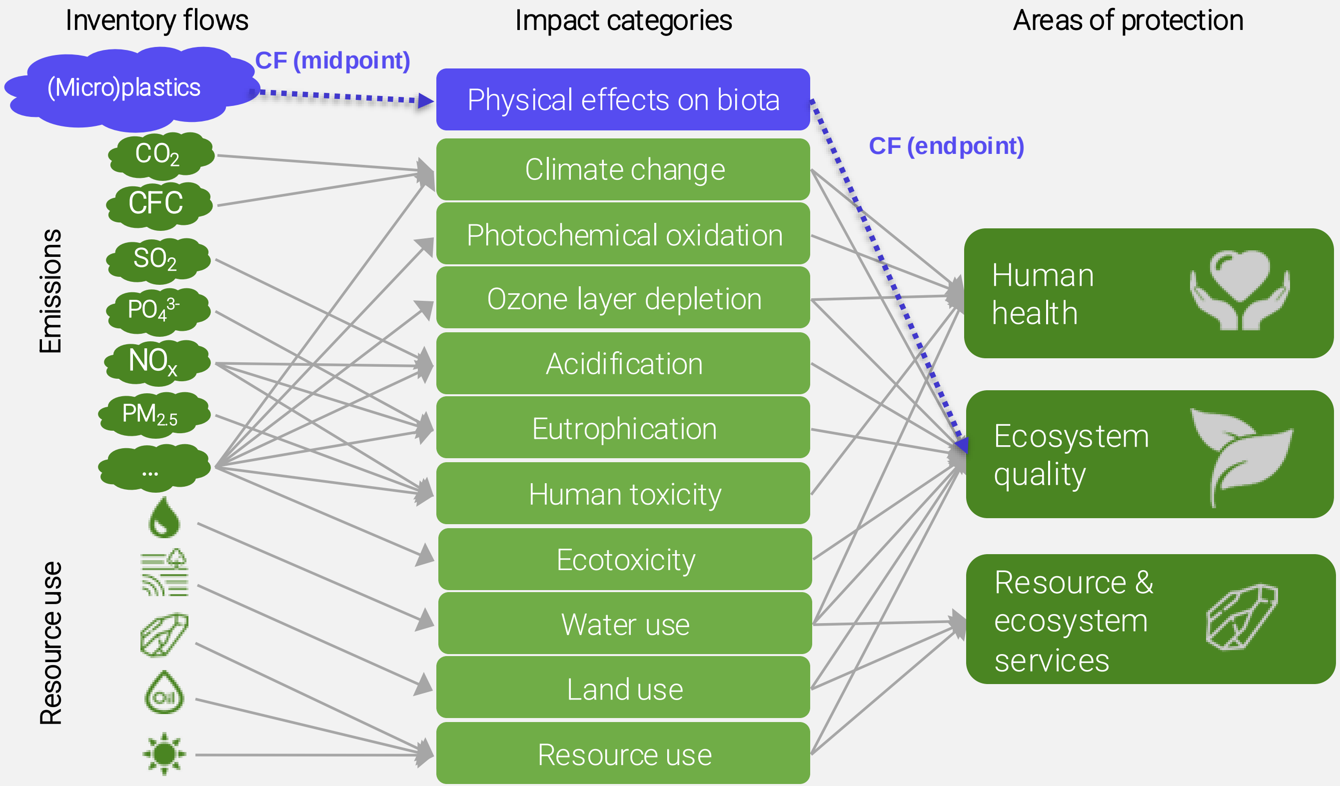
Impact category that aims at capturing the physical impacts of (plastic) litter on organisms, both through internal (ingestion) and external (entanglement, smothering) pathways.

Midpoints vs endpoints in LCA

Midpoints constitute intermediate steps in the cause-effect chain of an environmental impact category. They represent specific environmental problems like climate change, acidification, or human toxicity.

Endpoints represent the final consequences of environmental effects on protected areas like human health or ecosystem quality. They aggregate impacts from multiple midpoints into fewer categories.

Impact within LCA



This module focuses on the physical effects on biota of aquatic microplastic emissions and the ultimate potential damage on ecosystem quality (blue dotted arrows).

How are characterization factors established?

Microplastics Emissions
Measured in $kg_{\text{microplastic in compartment}}$

FF

Fate: environmental distribution and longevity.
The fate depends on the polymer type, shape and size. FF is measured in *days* spent in each compartment (water and sediments) and considers:

- Degradation
- Sedimentation
- Resuspension
- Deep burial

XF

Exposure: ingestion and entanglement by invertebrates, fish, seabirds and mammals.
The exposure relates the amount of microplastic found in a given environmental compartment to the amount of microplastic to which organisms are exposed. The conservative approach is XF = 1 $kg_{\text{bioavailable microplastic}}/kg_{\text{microplastic in compartment}}$.

EF

Effect: injury, suffocation, smothering and general debilitation; decreased food consumption, reduced ability to avoid predators etc.
Calculated using effect concentrations of 10%: the concentrations for which an effect is observed for 10% of individuals of a species. Data is collected in literature. EF is measured in $PAF.m^3/kg_{\text{bioavailable microplastic}}$

SF

Severity: links potentially affected fraction (PAF) of species with potentially disappeared fraction (PDF) of species.
The severity model was aligned with the GLAM methodology. SF is measured in PDF/PAF.

Midpoint characterization factors link the emissions of microplastics to their physical effects on biota impacts.

$$CF_{midpoint} = FF \cdot XF \cdot EF$$

Endpoint characterization factors link the emissions of microplastics to their damage to ecosystem quality.

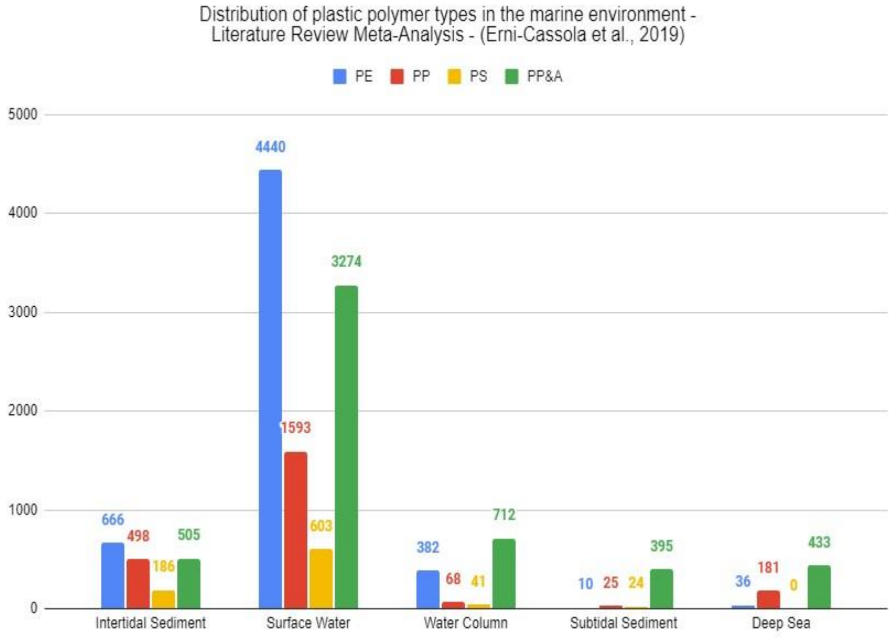
$$CF_{endpoint} = FF \cdot XF \cdot EF \cdot SF$$

Which polymers are commonly found in the marine environment?

A meta-analysis by Erni-Cassola ***et al***. (2019) highlights the distribution of various plastic polymers in the marine environment. The study observes four polymer types as the most commonly occurring polymers in the marine environment: Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), and Polyethylene Terephthalate (PP&A).

- **Intertidal Sediment:** The most common polymers found are PE (666 particles) and PP (498 particles), followed by PS (505 particles) and PP&A (186 particles).
- **Surface Water:** PE dominates significantly with 4440 particles, PP follows with 1593 particles, and PS has 603 particles. The least found is PP&A with 63 particles.
- **Water Column:** PE is also prevalent here with 382 particles, PP&A follows with 712 particles, while PS (41 particles) and PP (68 particles) are less common.
- **Subtidal Sediment:** The distribution shows a higher count for PP&A (712 particles), moderate for PE (395 particles), and lower counts for PP (24 particles) and PS (10 particles).
- **Deep Sea:** PP&A is predominant with 433 particles, while PS (181 particles) are less frequently encountered.

Overall, PE and PP&A are the most frequently detected polymers across various marine zones, indicating a widespread pollution problem.



Source: Erni-Cassola et al. (2019)

Existing LCA Characterization Factors (Literature Review)

This literature review focuses on CFs and FFs quantified and published across 24 journal articles.

Source	Quantifies CFs (Yes/No)	Description
Andrady, A. L. (2011).	No	Reviews the sources and effects of microplastics in the marine environment; focuses on distribution and environmental presence rather than quantifying impact.
Ashby, M. F. (2012).	No	Provides a guide to eco-informed material choices, discussing environmental impacts of materials broadly, not specific to plastics or quantifying impacts via CFs.
Barnes, D.K.A., et al. (2009).	No	Discusses the accumulation and fragmentation of plastic debris globally, focusing on observational data rather than specific lifecycle impact assessments.
Browne, M.A., et al. (2011).	No	Studies sources and sinks of microplastics on shorelines, focusing on distribution and environmental implications without lifecycle quantification.
Chitaka et al. (2020)	Yes	The study compares five options: plastic, paper, polylactic acid (PLA), reed, and bamboo. It uses life cycle assessment (LCA) methodology to assess their environmental performance based on factors like production, use, and disposal. The results indicate that reed and bamboo straws have the lowest environmental impact, while plastic and PLA straws have the highest. Additional analysis was done to understand the potential marine pollution impacts based on the leakage propensity of material and degradability from secondary data. Leakage rate: 38%. Added as an end-of-life flows for both PP and PLA. Degradability: • PLA and PP surface degradation rate: <10μm/year (Chamas et al., 2020) • PLA degradation rate: 29.2% in shallow zones and 24.6% in deep zones after 365 days (Beltrán-Sanahuja et al., 2020).
Civancik-Uslu et al. (2019)	Yes	The study uses life cycle assessment (LCA) methodology to assess their impacts from production to disposal. It introduces a new littering indicator (Littering Potential Index) to better understand the environmental consequences of improper disposal. The findings highlight that reusable bags, especially those made from fabric, have lower environmental impacts compared to single-use plastic bags.
Cole, M., et al. (2011).	No	Reviews the presence of microplastics in the marine environment and their potential impacts, more on ecological observations than lifecycle quantification.
Corella-Puertas, E., et al. (2023).	Yes	Provides actual CFs for microplastic impacts in life cycle assessments, focusing on physical effects on biota from emissions to aquatic environments.
Geyer, R., et al. (2017).	No	Discusses the global production, use, and fate of plastics, emphasizing statistical analysis of plastic production and waste management rather than specific impact factors.
Gregory, M.R., & Coe, J.M. (2009).	No	Focuses on the environmental impacts of plastic debris in marine settings, particularly physical entanglement, not lifecycle impact quantification.
Hale, R. C., et al. (2020).	No	Provides a global perspective on microplastics without specific CFs, focusing on broad environmental presence and potential impacts.
Hottle, T.A., et al. (2013).	No	Reviews sustainability assessments of bio-based polymers, focusing on general environmental considerations rather than specific impact quantification.
Jambeck, J.R., et al. (2015).	No	Analyzes plastic waste inputs from land into the ocean, focusing on waste management and plastic pollution statistics rather than impact assessment metrics.

Existing LCA Characterization Factors (Literature Review)

This literature review focuses on CFs and FFs quantified and published across 24 journal articles.

Source	Quantifies CFs (Yes/No)	Description
Laist, D.W. (1997).	No	Discusses impacts of marine debris with an extensive list of affected species, more on documentation of incidents rather than quantitative impact assessment.
Lithner, D., et al. (2011).	No	Assesses environmental and health hazards of different plastic polymers based on their chemical composition, not quantifying environmental impacts via CFs.
Maga et al. (2022)	Yes	Aims to integrate the potential risks caused by plastic emissions into Life Cycle Assessment (LCA) by proposing characterization factors (CFs) for plastic emissions. This methodology focuses on plastic pollution equivalents, measured by the residence time of plastics in the environment. The CFs are derived based on the Fate Factor (FF), which accounts for the residence time of plastic emissions in different environmental compartments. The study presents the calculated FFs for selected plastic emissions, expressed in plastic pollution equivalents per kilogram of plastic emitted. The study uses different time horizons (100, 500, and 1000 years) to illustrate how CFs vary over time. Longer time horizons reveal greater differentiation among plastic types based on their persistence.
Rochman, C.M., et al. (2015).	No	Studies the transfer of hazardous chemicals to fish through ingested plastics, focusing on toxicological data rather than CFs.
Salieri et al. (2021).	Yes	Quantifies the relevance of MP emissions, applying a simplified characterization factor (CF) to assess freshwater ecotoxicity. Calculates CFs for microplastics with different degradation rates (fast, average, and no degradation). Recommendation - Develop and validate CFs for freshwater and terrestrial ecotoxicity using frameworks like USEtox.
Stefanini et al. (2020)	Yes	Investigates the environmental impacts of various milk bottle types—PET, R-PET, non-returnable glass, and returnable glass—using Life Cycle Assessment (LCA) methodologies. They introduce a Marine Litter Indicator (MLI) to evaluate the potential pollution of these bottles when dispersed into the Mediterranean Sea. Provides CFs for different milk bottle types.
Thompson, R.C., et al. (2009).	No	Reviews plastics in the environment and human health, discussing broad impacts and trends without specific lifecycle quantification.
Wright, S.L., et al. (2013).	No	Reviews physical impacts of microplastics on marine organisms, more on ecological effects rather than quantifiable life cycle impacts.
Zanghelini et al. (2022)	No	The study compares plastic, paper, stainless steel, and bamboo straws using life cycle assessment (LCA) methodology. The results suggest that bamboo and stainless steel straws have lower environmental impacts compared to plastic and paper straws, especially when considering multiple uses and end-of-life scenarios. Additionally this study adopts a hybrid LCA method based on ReCiPe 2007 at mid-point level where marine litter was added as an impact category based on a leakage rate of 3.2% (Jambeck et al., 2015).
Zink, T., et al. (2016).	No	Discusses the role of industrial ecology in promoting a sustainable future, focusing on conceptual frameworks rather than specific quantification of impacts.

Why choose MariLCA CFs over other methodologies?

1. They match the polymers found in nature (slide 11) and the ones of interest to the industry (see survey results slide 22).

2. They can be used across different industries (i.e. much wider than specific objects like plastic bottles or straws).

3. They have both midpoint and endpoint CFs, and are compatible with different life cycle impact assessment methodologies.

4. They include detailed fate, exposure, effect and severity factors.

Recommended methodological approach

Methodology for assessing the potential impacts of microplastic leakage on ecosystem quality based on the MarILCA approach (marilca.org).

Primary and secondary data needed:

- Follow PFN microplastic modules to calculate the inventory of microplastic in the environment.

LCA characterization factors needed:

- To date (As of July 2024), the latest characterization factors are found in the article of Corella-Puertas et al. (2023). Updated CFs that include impacts in sediments will soon be available in the article of Saadi et al. (submitted), and are already available on marilca.org.
- As research evolves, updated and new characterization factors (i.e. for macroplastic leakage to marine water, microplastic leakage to soil, human health impacts) are expected to become available.

Always prefer LCA characterization factors for specific polymers, microplastic shapes and sizes

When the information on the type of plastic is not available, use the generic characterization factors.

Steps:

1. Collect primary data and compute microplastic release: Follow the steps of the PFN microplastic modules.
2. Calculate the impacts of microplastic release on ecosystem quality: Multiply the microplastic leakage by the characterization factors (CFs) as shown in the equation below.
   - If midpoint level CFs are used: the result will be the impacts of physical effects on biota in Potentially Affected Fraction of species (PAF).
   - If endpoint level CFs are used: the result will be the damage to ecosystem quality in Potentially Disappeared Fraction of species (PDF).
3. Integration into LCA (optional. recommended): Compute an LCA for various impact categories (climate change, water use, acidification, ecotoxicity, etc.) and integrate the results from step 2. Endpoint level results (damage on ecosystem quality) help to compare the magnitude of impacts from microplastic leakage to other impacts across the life cycle of a product or packaging.

$$Physical\ effects\ on\ biota\ (midpoint) = \sum_{\mathbf{microplastic\ type(polymer.shape.size)}} Leakage_{compartment} * Midpoint\ CF_{compartment.microplastic\ type}$$

With compartment = ocean. freshwater

$$Damage\ on\ ecosystem\ quality\ (endpoint) = \sum_{\mathbf{microplastic\ type(polymer.shape.size)}} Leakage_{compartment} * Endpoint\ CF_{compartment.microplastic\ type}$$

With compartment = ocean. freshwater

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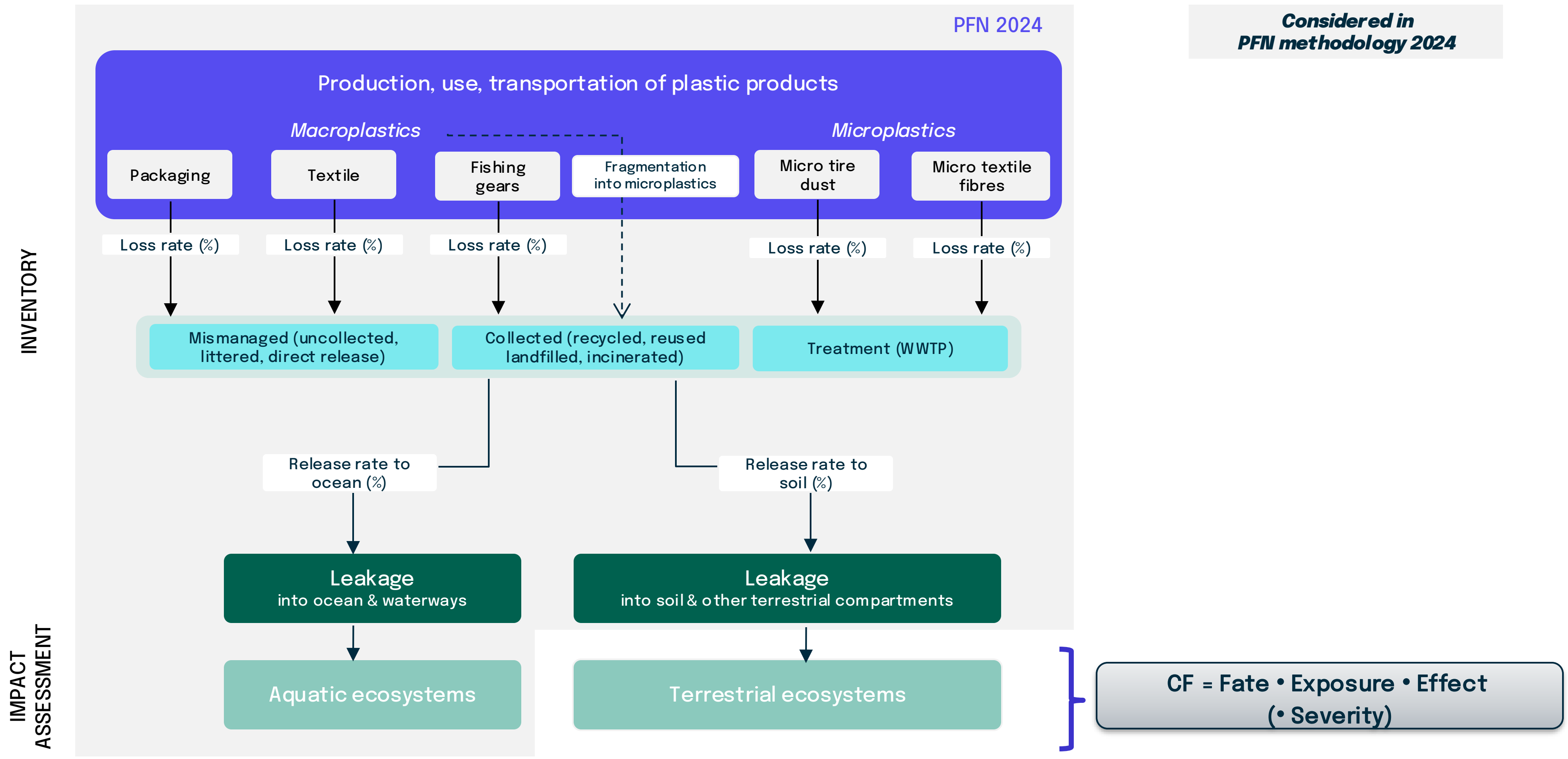
Part. 2

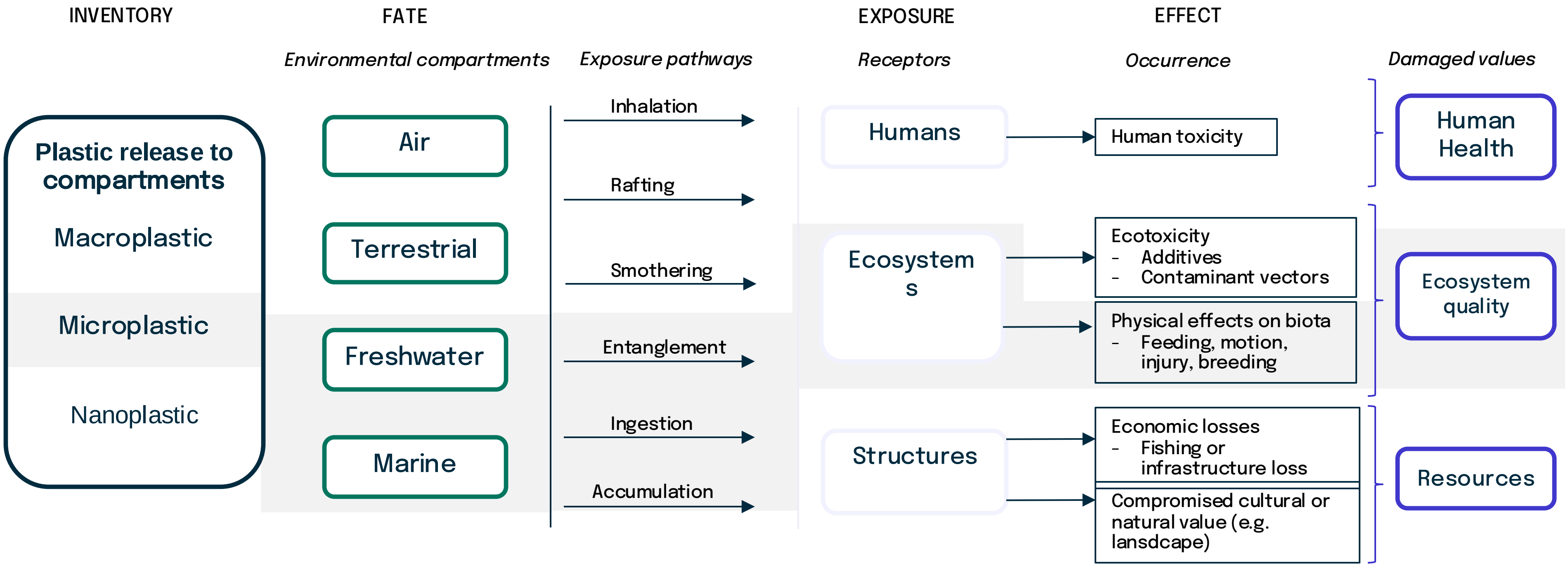
System map & calculation routes

The different elements to take into account during an impact assessment in the context of the plastic footprint.
How these elements interact? Which calculation routes to follow?

System map


PFN 2024
Production, use, transportation of plastic products
Macroplastics
Microplastics
Packaging
Textile
Fishing gears
Fragmentation into microplastics
Micro tire dust
Micro textile fibres
Loss rate (%)
Loss rate (%)
Loss rate (%)
Loss rate (%)
Loss rate (%)
INVENTORY
Mismanaged (uncollected, littered, direct release)
Collected (recycled, reused landfilled, incinerated)
Treatment (WWTP)
Release rate to ocean (%)
Release rate to soil (%)
Leakage into ocean & waterways
Leakage into soil & other terrestrial compartments
IMPACT ASSESSMENT
Aquatic ecosystems
Terrestrial ecosystems
Considered in PFN methodology 2024
CF = Fate • Exposure • Effect (• Severity)

Impact pathway



Sources: adapted from Woods et al. (2021)

Considered in PFN impact methodology 2024

Calculation routes

Midpoint level

$$Physical\ effects\ on\ biota = \sum_{microplastic\ type\ (polymer.\ shape.size)} Leakage_{compartment} * Midpoint\ CF_{compartment.microplastic\ type}$$

With compartment = ocean. freshwater

Symbol	Description	Unit	Value	Reference	Additional comments
$Leakage_{compartment}$	Mass of microplastics leaked into compartment	Kg	Calculated from inventory methodology for each type of microplastic	PFN_Inventory 2023	Assessment of the mass of microplastics from a given source emitted to an environmental compartment using the inventory methodology established by the PFN.
$Midpoint\ CF_{compartment.microplastic\ type}$	Characterization factor at the midpoint level	PAF*m³*day/kg emitted	Retrieved from a CF database	MarILCA website	Calculated by combining the fate, exposure, and effect factors related to a type of microplastic emitted into a compartment, the CF is specific to this microplastic type (page 10). The **Potentially Affected Fraction (PAF) of species** is the unit of the effect factor and is calculated from the species sensitivity distribution (SSD) for microplastics. It is an estimate of the proportion of the species within the ecosystem damaged by that concentration of the substance.

Endpoint level

$$Damage\ on\ ecoystem\ quality = \sum_{microplastic\ type\ (polymer.\ shape.size)} Leakage_{compartment} * Endpoint\ CF_{compartment.microplastic\ type}$$

With compartment = ocean. freshwater

Symbol	Description	Unit	Value	Reference	Additional comments
$Leakage_{compartment}$	Mass of microplastics leaked into compartment	Kg	Calculated from inventory methodology for each type of microplastic	PFN_Inventory 2023	Assessment of the mass of microplastics from a given source emitted to an environmental compartment using the inventory methodology established by the PFN.
$Endpoint\ CF_{compartment.microplastic\ type}$	Characterization factor at the endpoint level	PDF*m²*year/kg emitted	Retrieved from a CF database	MarILCA website	Calculated by combining the fate, exposure, and effect and severity factors related to a type of microplastic emitted into a compartment, the CF is specific to this microplastic type (page 10). The **Potentially Disappeared Fraction (PDF) of species** indicates a change in species diversity due to an environmental pressure and is integrated over a certain timeand area. It is converted from the PAF through a severity factor.

Part. 3

Models and background data

The LCA characterization factors needed to perform the assessment.

PFN

MarILCA characterization factors

MariLCA CFs are available for use in LCA for

- For **11 polymers**: PET, HDPE, EPS, PVC, LDPE, PP, PS, PA (Nylon), PHA, PLA, TRWP (Tire and Road Wear Particles)
- Of **3 different shapes**: Beads/Unspecified fragments, Film Fragments and Fibers,
- and **5 different sizes**: 1μm, 10μm, 100μm, 1000μm and 5000μm.

CFs to be used in impact assessment should be chosen based on the characteristics of the microplastics emitted.

These CFs assume that:

- The marine environment is a homogenous box at steady state.
- Degradation occurs mainly on the microplastic surface.
- The effect of microplastics is independent of the polymer, size and shape (Lavoie et al. 2021).
- The fate of microplastics depends on the polymer, size and shape.

Conversion to other units is possible for use in other life cycle impact assessment methods, such as ReCiPe or GLAM. So far, CFs in units of PDF.yr/kg compatible with the GLAM method are available on www.marilca.org, and the conversion to ReCiPe is available upon request.

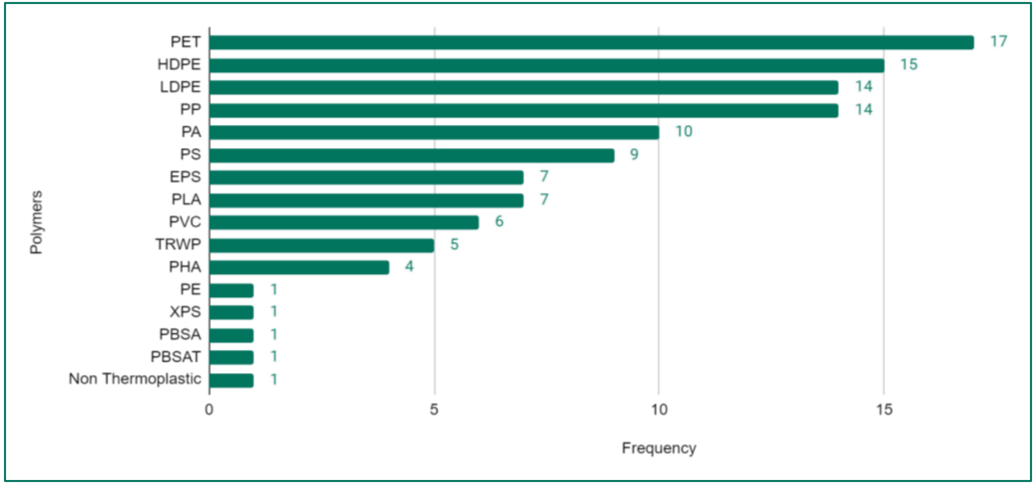
CF are based on current industry needs

To align the chosen CFs with current industry needs, we conducted a survey with 17 experts and industry leaders from the PFN to understand the most frequently used polymers in the field.

Polymers (MarILCA)*

- PET
- HDPE
- EPS
- PVC
- LDPE
- PP
- PS
- PA (Nylon)
- PHA
- PLA
- TRWP (Tire and Road Wear Particles)

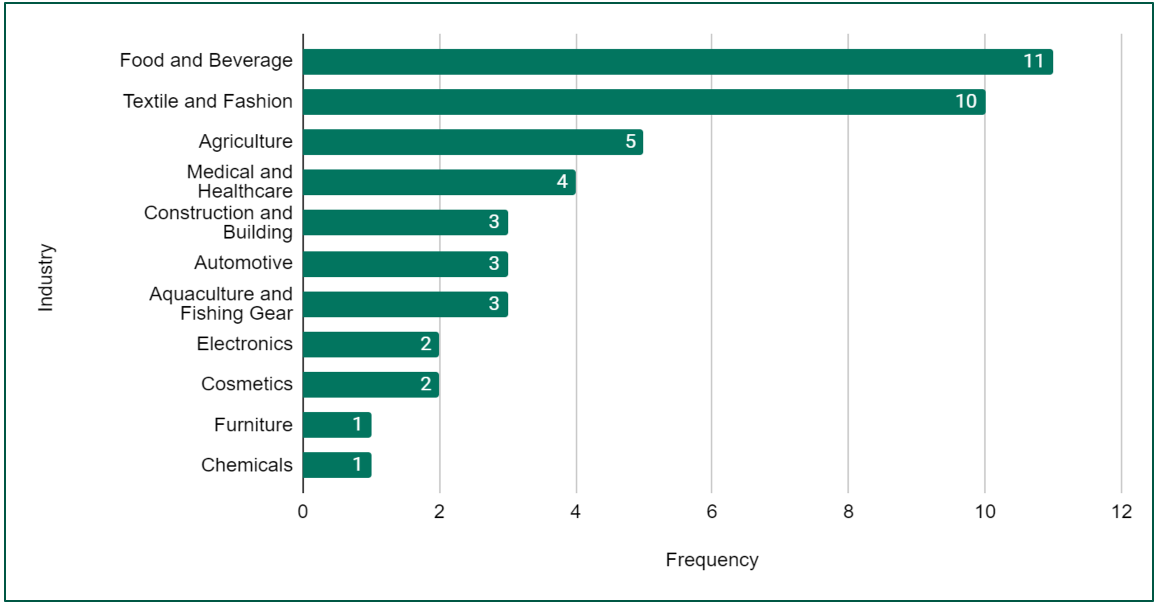
Frequently used polymers within various Industries



*MarILCA characterization factors (Corella-Puertas et al. 2023)

To understand the industry's needs for data on the shapes and sizes of microplastics, we analyzed the demographics of our respondents. This group, primarily consisting of consultants, scientists, users, and technology providers, revealed the most common sectors involved in the quantification of plastic footprints.

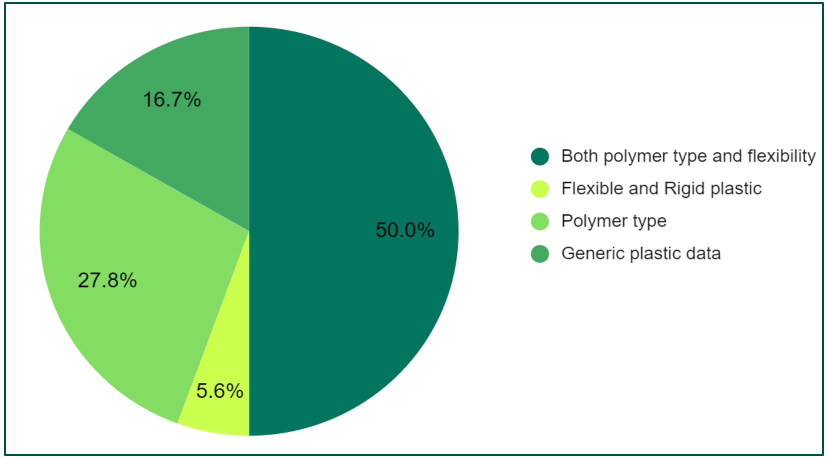
Industries engaged on plastic footprinting



Data granularity gaps

Following the Data Governance Technical Module on Data Granularity, we collected information to understand the industry's current state of data quality. While 70% of companies have information on polymer type, a significant number do not, as they only have data on flexibility or generic plastic data. Thus, this working group researched whether CFs could be provided for generic rigid and flexible plastics. The outcome was that "rigid vs flexible" is not sufficient information to provide generic CFs. The reason is that the fate of microplastics in aquatic environments is highly dependent on the polymer density, and there are rigid and flexible plastics of different densities. If a microplastic impact assessment needs to be done despite the lack of data on the polymer type and density, the conservative approach would be to choose the generic low-density CFs, as these are linked with higher potential impacts than higher-density polymers.

Plastic inventory data of Industries based on the granularity indicator



Currently, CFs are available for generic data, with the requirement that the polymer density must be known.

For unspecified plastics, the conservative approach would be to choose the generic low-density CFs.

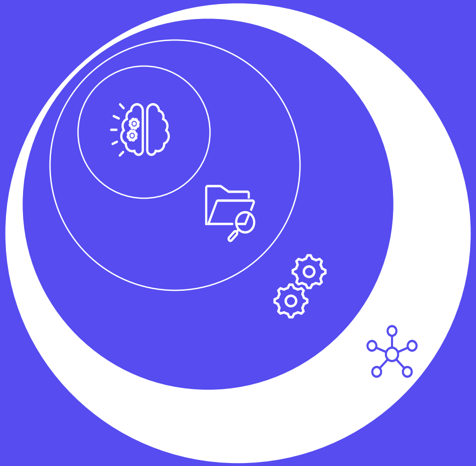
Current Generic CFs

- High-density polymer > 1.1 g/cm^3
- Medium-density polymer 0.8-1.1 g/cm^3
- Low-density polymer < 0.8 g/cm^3

Part. 4

Case study

An illustrative example of how to apply the methodology.



Objective and system boundaries

Objective of the case study

This case study serves as an example of how to assess the potential impacts of microplastics using the PFN methodology. First, the inventory is calculated using the PFN modules from 2023. Then the corresponding physical effects on biota, and ultimate damage to ecosystem quality are assessed following the present methodology.

The purpose of this case study is to display how the PFN modules can be used together to evaluate the microplastic footprint.

System considered

This case study focuses on the life cycle of a synthetic T-shirt, covering cradle to use. Several types of microplastic emissions (microfibers; tyre dust from transportation) are included. The T-shirt is manufactured in China, then transported and used in Europe.

To be representative, polyester fiber was chosen for the study, which accounts for 54% of global textile fibre production in 2021 (Textile Exchange, 2022). The average weight of a T-shirt is 150 grams.

Microplastic Losses

The microplastic losses occure during:

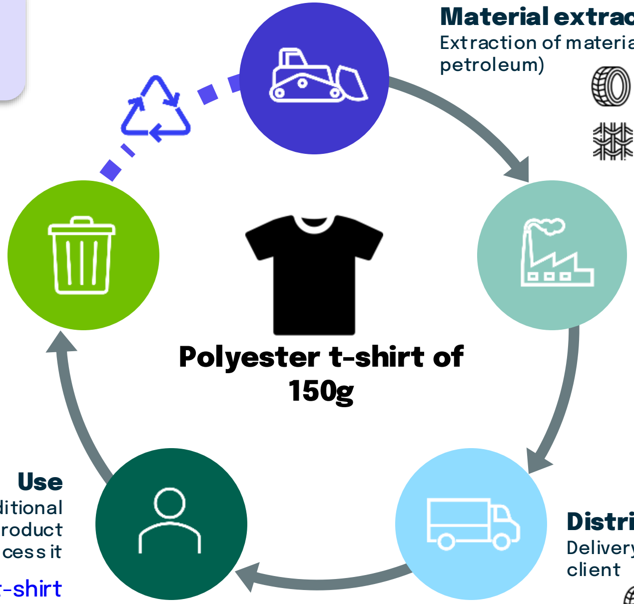
- The transport of raw materials to the manufacturing plant
- The production of the t-shirt, including the processes for which loss rates were determined in the PFN textile module of 2023 (i.e. scouring, dyeing, rinsing, etc.)
- The transport of the t-shirt to the company and to the user
- Use and washing of the t-shirt

The stages for which losses of microplastics are not taken into account are :

- Extraction and manufacture of T-shirt raw materials
- The storage
- The end-of-life of the T-shirt

Case study scope: production and use of a polyester t-shirt

Plastic leakage:
- **textile fibers** from production and use
- **tire wear particles** from transportation



Material extraction & processing
Extraction of materials from the ground (such as ores and petroleum)
- Transport of raw materials to the manufacturing plant in China
- Extraction and manufacture of T-shirt raw materials

Manufacturing
Processing of materials and manufacturing of the product
- Knitting/weaving, scouring, dyeing. Rinsing, heat setting, brushing (inputs, energy, emissions, waste, etc.)
- Process scrap

Distribution
Delivery of the product to the client
- Transport to the company site in Spain
- Transport to the store and customer in France
- Storage

Use
Consumption of additional resources to use the product or further process it
- Use and washing of the t-shirt

End of life
Discard of the product with various pathways (incineration, recycling, recover of energy…)
- T-shirt end-of-life in Europe

Included
Not included

Micro textile fiber
Micro tire dust

Case study: methodology and data needed

Primary data: Primary data is information obtained directly from the source, often through methods like weighing quantities conducted by the company itself. It is highly precise and specific but requires significant effort to collect.

Secondary data: Conversely, secondary data is derived from external sources, such as literature and external data repositories, to include various factors in calculations. While it is easier to produce, it tends to be less precise compared to top-down data.

The equation parameters below are defined on page 30 (primary parameters) and on page 31 (secondary parameters)

Used methodologies

- PFN_module_Microplastic_Textile_2023_10_13

Production: $Leak_{compartment} = M_{textiles}(t) * share_{synthetic}(\%) * \#process * LR_{process}(\%) * RR_{country,compartment}(\%)$

Use: $Leak_{compartment} = M_{garment\ type}(t) * share_{synthetic}(\%) * \#wash_{garment\ type} * LR_{use}(\%) * RR_{country,compartment}(\%)$

- PFN_module_Microplastic_Tires_2023_10_13

$$Leak_{compartment} = N_{type}(\#vhc) * D_{vhc\ type}(km) * \frac{M_{good,type}(kg)}{Load_{av,vch\ type}(kg)} * LR_{type}\left(\frac{kg}{vhc * km}\right) * RR_{compartment}(\%)$$

- This module (impact methodology)

$$Physical\ effects\ on\ biota\ (midpoint) = \sum_{\text{microplastic type}(polymer.shape.size)} Leakage_{compartment} * Midpoint\ CF_{compartment.microplastic\ type}$$

$$Damage\ on\ ecosystem\ quality\ (endpoint) = \sum_{\text{microplastic type}(polymer.shape.size)} Leakage_{compartment} * Endpoint\ CF_{compartment.microplastic\ type}$$

PFN

Case study: description of parameters

Primary data

	Symbol	Description	Unit	Value	Reference	Additional comments
TEXTILES	$M_{textiles}$	Mass of the textile product, in the production stage	Kg	Primary data, for this case study = 0.150	n/a	Estimation of the typical mass of a t-shirt
	$M_{garment\ type}$	Mass of the textile product, in the use stage	Kg	Primary data, for this case study = 0.150	n/a	Estimation of the typical mass of a t-shirt
	$share_{synthetic}$	Percentage of synthetic fibers in the product	%	Primary data, for this case study = 100	n/a	
	$\#process$	Iteration of different processes	#	Primary data, for this case study = 1	n/a	All considered processes are Scouring, Dyeing, Rinsing, Heat setting; 1 time each
	$\#wash_{garment\ type}$	Number of times each product is washed in its lifetime	#	Primary data, for this case study = 45	PFN_Inventory 2023	
TIRES	N_{type}	Number of vehicle of the considered category	# vhc	Primary data, for this case study = 1 heavy truck of 32 t	n/a	
	$D_{vehicletype}$	Distance travelled on the road by a vehicle of the considered category	Km / vhc	Primary data, for this case study = 2742	n/a	240 km from Shaowing to Shanghai + 964 km from Valencia to Barcelos + 1538 km from Barcelos to Lyon
	$M_{goodtype}$	Mass of product transported over the distance D_vehicle type	Kg	From primary data, for this case study: 0.150	n/a	

Case study: description of parameters

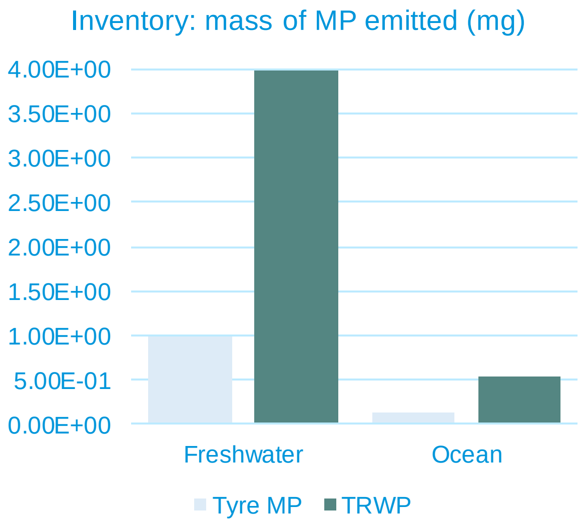
Secondary data

	Symbol	Description	Unit	Value	Reference	Additional comments
TEXTILES	$LR_{process}$	Loss rate during the production processes	%	From secondary data	PFN_Inventory 2023	It depends on the process. Specific values exist for dyeing, scouring, rinsing, and heat setting.
	LR_{use}	Loss rate during household washing	%	From secondary data	PFN_Inventory 2023	Can be tuned according to textile and washing parameters.
	$RR_{country, compartment}$	Release rate to environmental compartments	%	From secondary data	Values used in the PFN_Inventory 2023	Country specific: release in ocean and waterways depends on the presence and type of WWTP; release in soil and terrestrial compartments depends on the fate of the sewage sludge.
TIRES	$LR_{vehicle\ type}$	Loss of microplastic from tires of the vehicle of the considered type	Mg / (vhc*km)	From secondary data; in this case study: 516 mg/km (high value chosen)	PFN_Inventory 2023	
	$Load_{av\ type}$	Load of the vehicle considering the load of the transported merchandise	Kg	From secondary data; in this case study: 32 000 kg (for a 32t truck with a filling rate of 100%)	Values from the PLP Guidelines and Load factors from Merchan Arribas, A. (2019)	
	$RR_{compartment}$	Release rate to environmental compartments	%	From secondary data	Values from the PLP Guidelines used in the PFN_Inventory 2023	

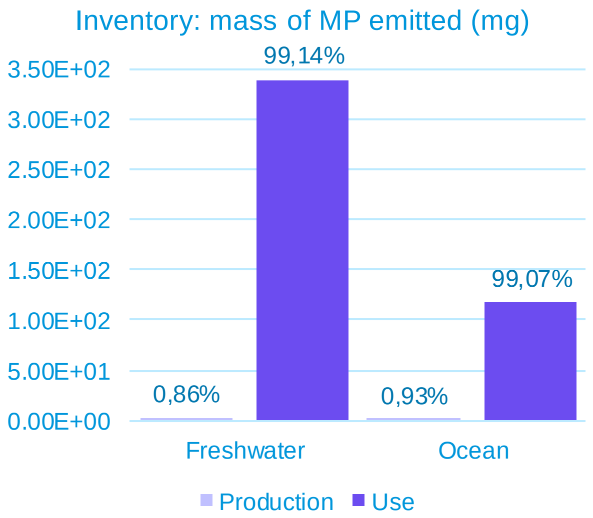
Inventory of emissions in freshwater and ocean

Tested modules:

Micro (Tyres)



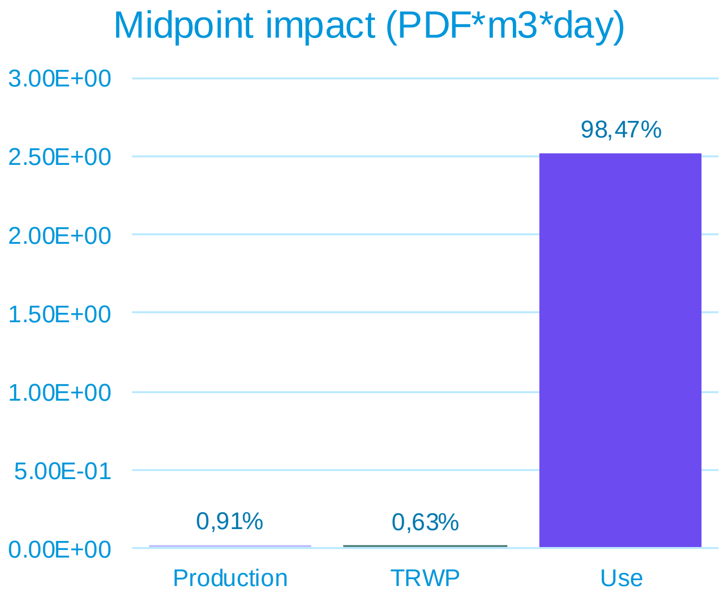
Micro (Textile)

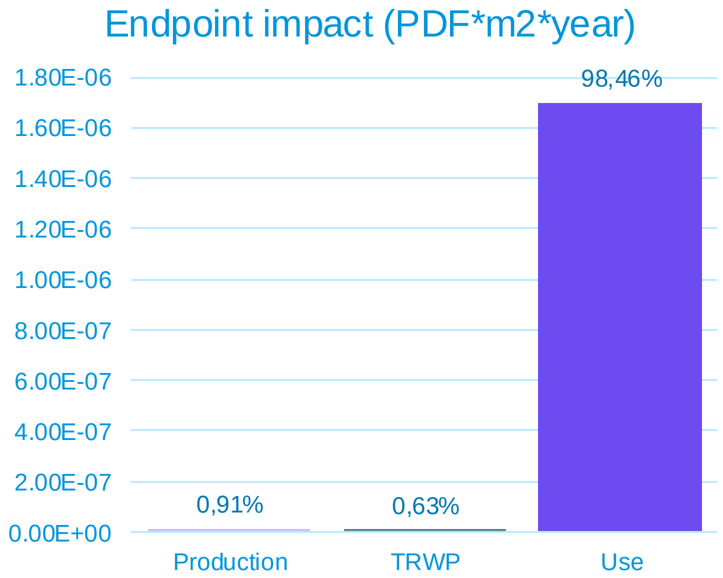


*Utilized CFs were determined for **TRWPs**, i.e. Tyre and Road Wear Particles, which comprise tyre wear particles (TWP) and road wear particles. Here, Tyre MP accounts for the microplastic part of TWP and is estimated from the share of polymer in tyre (see PFN_data_11_2023_v2-1). Hence, the mass of TWP (i.e. Emission factor in PFN_data_11_2023_v2-1) is obtained through: LR (loss rate)/Sh (share of polymer in tyre). Finally, considering a 50% share of TWP and road wear particles in TRWP, the mass of TRWP = 2*TWP. For HDVs, mass of TRWP = 4* mass of tyre MP because Sh = 50%.

Further research is needed to include the leakage of microfibers at the end of life of textiles. First results indicate that weathered fabrics could release 20-40 times more microfibers than washing only (Pinlova & Nowack 2023).

Case study: Microplastics impact





The potential impact of microplastics is **1.73E-06 PDF*m²*year** (98% due to use). However, this result is marginal compared to the potential impact of the T-shirt. The production and extraction of raw materials stages already account for 9.75 PDF*m²*year.

General conclusions on the importance of microplastic impacts should not be drawn from a single case study.

Part 5.

Outlook

Future research and methodology developments

Future research opportunities

Data Gaps:

Issue: Insufficient CFs for new materials like bioplastics, and for potential impacts of all types of plastics on terrestrial ecosystems.

Action: Expand research to include materials like bioplastics, reflecting modern usage trends. Develop CFs for leakage to soil & other terrestrial compartments.

Variable Conditions:

Issue: Current CFs are global and do not fully account for regional differences such as temperature and UV exposure, which significantly influence the degradation rates and behaviors of plastics.

Action: Develop models that incorporate dynamic and regional environmental variations.

Circular Economy Inclusion:

Issue: CFs must evolve to assess the impacts of not just material production but also their reuse, recycling, and end-of-life stages. At the moment, CFs are not available for recycled plastics, which might have different degradation properties than virgin plastics.

Action: Adapt CFs to evaluate all life cycle stage, promoting sustainability across the product lifecycle.

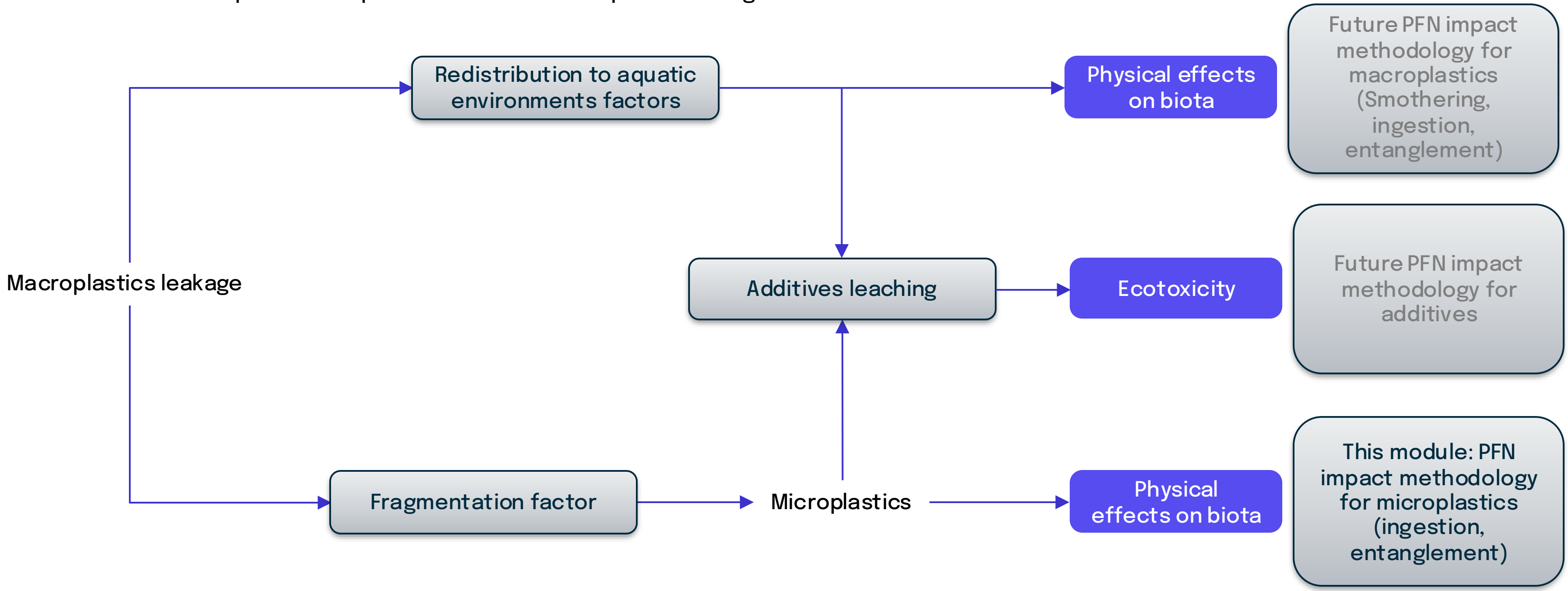
Simplification for Policy Development:

Issue: CFs' technical nature limits their direct use in policy-making. They need alignment with the real-world needs of policymakers to enhance decision-making in environmental and plastic management.

Action: Simplify CFs for broader understanding, incorporate socio-economic factors to evaluate the full impact of waste management strategies, and enhance CFs with predictive tools for scenario analysis, enabling proactive policy development.

Macroplastic outlook

How to calculate the potential impacts linked with macroplastic leakage.



Fragmentation factor and the leaching of additives are currently researched and not readily available.

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Plastic Footprint Network

convened by EA - Earth Action

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Our commitment to continuous improvement

The Plastic Footprint Network's successful collaboration is built on pillars of:

- Open
- Non-competitive and productive dialog
- Leveraging science and supporting ongoing research
- Broadly empowering global stakeholders (product manufacturers, brand owners, treaty negotiators, regulators, consultants, NGOs, etc.) to effectively do their part to address the plastic pollution crisis.

Given corresponding commitments to transparency and continuous improvement, we welcome and encourage your feedback and input on this document so that the methodology can continue to be enhanced and refined.

Thank you for supporting the work of the Plastic Footprint Network.

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