PRE-PRINT: MODULE UNDER SCIENTIFIC COMMITTEE REVEW

Plastic Footprint Guidelines

Module on microplastic - agriculture

Version 1. December 2024

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

Introduction to the Plastic Footprint Network

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

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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 evaluate the current state of the science and available methodologies for evaluating the impact of microplastics derived agriculture. The module brings forward a first calculation approach based on available data. The main outcomes are:

1. List the publications and identify how they can be used to feed the inventory methodology
2. Identify the fluxes and gather rationales to prioritize their relative importance
3. For fluxes for which data is available propose a first draft for calculation routes and secondary datasets

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

Future objectives for 2025 include:
Linking the methodology to impact module
Refining the methodology including more sources and characteristics

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)

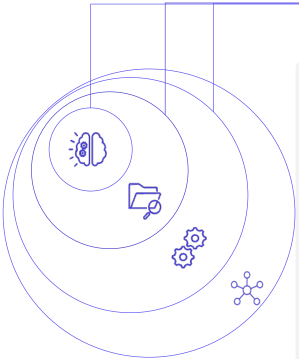
Inventory: Microplastics

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

Impact

- Impact MariLCA (new)

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 Outlook

Future prospects conclusions and perspectives looking forward

Target audience: busy readers, scientific journalists

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.

Supporting information

Reviewing the sources and effects of leakage from agricultural activities

Sources of leakage

Negative effects of contamination

An overview of plastic leakage sources in agriculture

Plastic use in agriculture has grown significantly over the past decades, driven by its affordability, durability, and utility in enhancing productivity. However, these benefits come with environmental concerns, particularly plastic leakage into ecosystems, where it can persist for decades, causing harm to soil health, water quality, and biodiversity. Plastic leakage from agricultural soils can originate from direct sources, where plastic is intentionally introduced but inadequately managed, or indirect sources, where plastic enters the environment unintentionally through degradation or secondary contamination.

Direct and obvious sources :

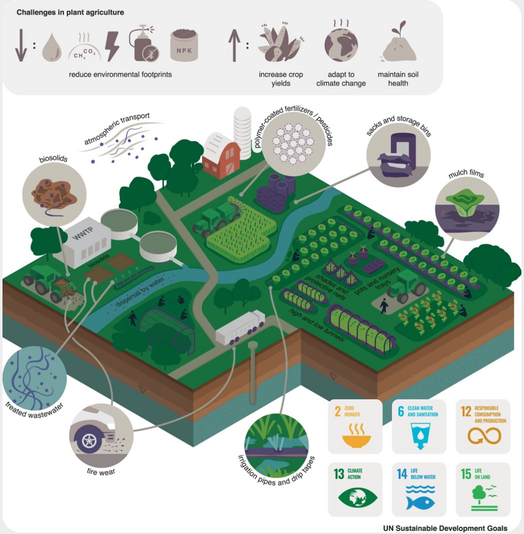
- Mulching films
- Protecting nets
- Greenhouses
- Irrigation pipes
- Bags and other packagings

These macroplastics break down into microplastics over time due to weathering, mechanical stress, and biological activity.

Indirect and less obvious sources :

- Organic fertilizer products (composts, manure and WWTP sludges)
- Fertilizer/Pesticide Encapsulants
- Water
- (Tyre abrasion)

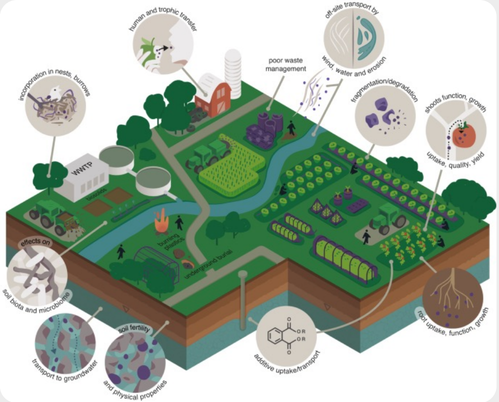
PFN modules Micro textile and Tyres



[1] 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

What are the negative effects and risks associated to plastics contamination in agricultural soils?

- Microplastics are not the only stressors acting on agricultural ecosystems. Many global change stressors are acting concurrently on agricultural ecosystems, including physical (e.g., warming), chemical (e.g., pesticides), and biological (e.g., invasive plant species or weeds) stressors. Recent work suggests that the combined pressures and the high number of factors acting on agricultural soils can lead to unpredictable effects in the soil ecosystem [2,3]
- Microplastics can be absorbed by organisms, disrupting microbiome functions. Understanding the potential for plastics and leached additives to accumulate in plants and enter the food chain is crucial for safeguarding food safety and human health.
- Microplastics have been shown to negatively affect the growth of crops and animals (e.g., ciliates, flagellates), and cause soil bacterial community structure dysbiosis. [4,5]
- Leaching of additives from plastics increases the chemical burden on soils. The consequences of a long-term release of chemicals due to the degradation of plastics in soils are unknown [6]

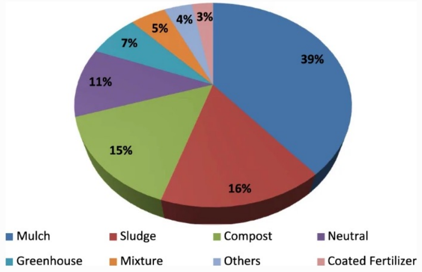


[1] Hofmann, T., Ghoshal, S., Tufenkji, N. et al. Plastics can be used more sustainably in agriculture. Commun Earth Environ 4, 332 (2023). https://doi.org/10.1038/s43247-023-00982-4

Research in microplastics and agriculture

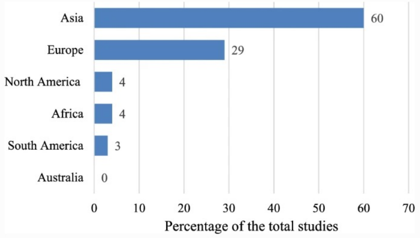
- Plastic is found in many types of crops and agricultural land: arable lands, paddy lands, uplands, irrigation, and greenhouse soils.
- Significant sources of plastic contamination in the agricultural soils includes mulching, sludge and compost placement, and greenhouses abandonment.
- Most research studies have been carried in Asia and Europe.
- The amount of microplastics released depend on:
  - The type of source
  - The geographical region
  - The crop category
  - The type of site (urban area versus remote countryside)
  - Differences in land management, soil, geomorphology,
- Models do often not take into account the size, type of polymer or shape of microplastics. The databases used contain large uncertainties and the method only gives estimates.

Fig. 2



Sources of microplastics in agricultural soils (n = 120)

Fig. 1



Worldwide distribution of plastics studies conducted on agricultural land (n = 120)

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Sa'adu et al., 2023

Characteristics of plastic pollution in agricultural soil

Soil contamination varies along soil profile with a clear decrease from -20cm to -90cm. (Kedzierski et al., 2023)

Global median stock of microplastics in soils could be of the order of 3.6 Mt., which is one to two orders of magnitude higher than what has been estimated for microplastic stocks at the ocean surface. (Kedzierski et al., 2023)

Methodologies and measurement methods vary across the literature leading to different values and conclusions. (Buks et al., 2020).

Impact of historical practices on soil contamination: soils in many agricultural regions now contain significant plastic residues accumulated over the decades (Cusworth et al., 2024)

Concentrations of microplastics in agricultural soils increase over time and the application of organic and inorganic fertilisers are significant contributors of microplastics. (Cusworth et al., 2024)

Country	Plastic source	Soil type	Crop(s)	Abundance		Composition	References
				Macro	Micro		
Hungary	Greenhouse	Arable land	Tomatoes	6.4 kg h^{-1}	225 ± 61.69 pieces kg^{-1}	PE, PVC, and PP	[36]
China	Mulch	Arable land	Maize	6796 ± 1070 pieces m^{-2}	8885 and 2899 pieces kg^{-1}	PE, PP, and PET	[57]
China	Mulch	Upland land	Maize		754 ± 477 items kg^{-1}	PP, PE, PET, and PES	[52]
China	Sludge	Paddy land	Rice and wheat		149.2 ± 52.5, 68.6 ± 21.5, and 73.1 ± 15.4 particles kg^{-1}	PES, PP, and PS-AC	[22]
China	Plastic gauze	Arable land	NA		1629.68 tons $year^{-1}$	NA	[26]
Japan	Coated fertilizer	Paddy land	Rice		144 mg kg^{-1}	PE	[37]
Thailand	Mix	Mix	Cabbage, pumpkin, guava, etc.		12–117 items m^{-2}	PE, LDPE, PP, and PS	[59]
India	Mulch	Arable land	Tomatoes		37.97%, 35.07%, and 36.99% plastic residue	NA	[61]
Korea	Mix	Mix	Rice and vegetables		664 pieces kg^{-1}	PE and PP	[66]
Switzerland	Mulch	Drainage water	Vegetables		10.5 ± 9.5 N L^{-1}		[70]
Germany	Sludge	Arable land	NA		14.6 MP g^{-1}	PES, PA, PVC, PAN, etc.	[51]
Greece	Film	Greenhouse	Watermelon and tomatoes		301 ± 140 and 69 ± 38 items kg^{-1}	PE and BMF	[54]
Spain and Netherland	Mix	Mix	Broccoli, celery, and watermelon		2242 ± 984 and 888 ± 500 MPs kg^{-1}	NA	[43]
Switzerland	Organic compost	Arable land	NA		22.4 ± 3.3 tons $year^{-1}$	NA	[71]
Tanzania	N.A	Irrigation land	NA	0.5–5.5 kg	0.21–1.50 items g^{-1}	PET, HDLE, LPE, PS, etc.	[53]
Mauritius	Mix	Arable land	Vegetables		320.0 ± 112.2 and 420.0 ± 244.0 particles kg^{-1}	PP and PA	[56]
Tunisia	Mix	Mix	NA		13.21 ± 0.89 to 852.24 ± 124.2 items kg^{-1}	PEVA, PE, PBAT, and PP	[25]
Chile	Mix	Mix	NA		306 ± 360–184 ± 266 particles kg^{-1}	PE, PP, and PS	[62]
Canada	Biosolid	Arable land	NA		4.1 × 1011 and 1.3 × 1012 particles	PE, PP, PS, etc.	[58]
Mexico	Mulch	Arable land	NA		400–2000 particles kg^{-1}	LDPE	

Sa’adu et al., 2023

Methods by sources

These methods can be used for other regions and adapted when more knowledge and data become available.

Brandes, Elke, Martin Henseler, and Peter Kreins, 2021. Identifying Hot-Spots for Microplastic Contamination in Agricultural Soils–a Spatial Modelling Approach for Germany. Environmental Research Letters 16, 104041. https://doi.org/10.1088/1748-9326/ac21e6.

1) Estimations of the amounts of MP entering agricultural soils through sewage sludge in Germany

Method : $\mathrm{MP}^{SL}_{i2016} = C^{SL}_{2016} \times M^{SL}_{i2016}.$ (1)

MP masses in mg = national mean MP concentration in sewage sludge in wt% (0,56 wt% for Germany) * sewage sludge masses produced for agricultural per region
Could be used as follows :
- Establish secondary data by geographical region on the **MP concentration in sewage sludges**
- Establish secondary data by geographical region on the **mass of sewage production**
- Establish secondary data by geographical region on the **proportion of sewage sludge discharged into agricultural soil** (the PFN already has secondary data?)

2) Estimations of the amounts of MP entering agricultural soils through compost in Germany

Method : $\mathrm{MP}^{CO}_{i2016} = M^{CO}_{i2016} \times C^{CO}.$ (9)

MP masses in mg = compost amounts produced for agricultural use per region * national mean MP concentration in compost wt% (0,037 wt% for Germany)
Could be used as follows :
- Establish secondary data by geographical region on the **MP concentration in compost**
- Establish secondary data by geographical region on the **mass of compost production**

Mulch films and cover tarps

Brandes, Elke, Martin Henseler, and Peter Kreins, 2021. Identifying Hot-Spots for Microplastic Contamination in Agricultural Soils–a Spatial Modelling Approach for Germany. Environmental Research Letters 16, 104041. https://doi.org/10.1088/1748-9326/ac21e6.

3) Estimations of the amounts of MP entering agricultural soils through mulch films and cover tarps in Germany

Method :

$$\mathrm{MP}_{i2012}^{SC} = A_{i2012}^{SC} \times AP_{2012}^{SC} \times L^{SC} \times FM^{SC}, \qquad (13)$$

Crop category	AP_{2012}^{SC}	L^{SC}	TH (m)	D^{LDPE} (kg m^{-3})	FM^{SC} (kg ha^{-1})
ASP	1.0	0.0010	0.000 100	917.5	917.500
STR	0.5	0.0027	0.000 040	917.5	367.000
CUC	1.0	0.0094	0.000 030	917.5	275.250
LET	0.5	0.0100	0.000 025	917.5	229.375
EPO	1.0	0.0100	0.000 025	917.5	229.375

MP masses in mg = area of the speciality crop category grow … d * loss factor * mass of foil per ha (= thickness * 10 000 * D_LDPE)

Crop categories are: asparagus, strawberries, cucurbits (including cucumbers, summer squash, and winter squash), lettuce, and early potatoes.

Could be used as follows :
- Establish secondary data by geographical region on the **area of agricultural soils**
- Establish secondary data by geographical region on the **distribution of crop categories**

- Establish secondary data on **the fraction of the area where mulch film or cover tarp is used per crop category**
- Establish secondary data on **loss factors**
- Establish secondary data on **thickness of foil per crop category**

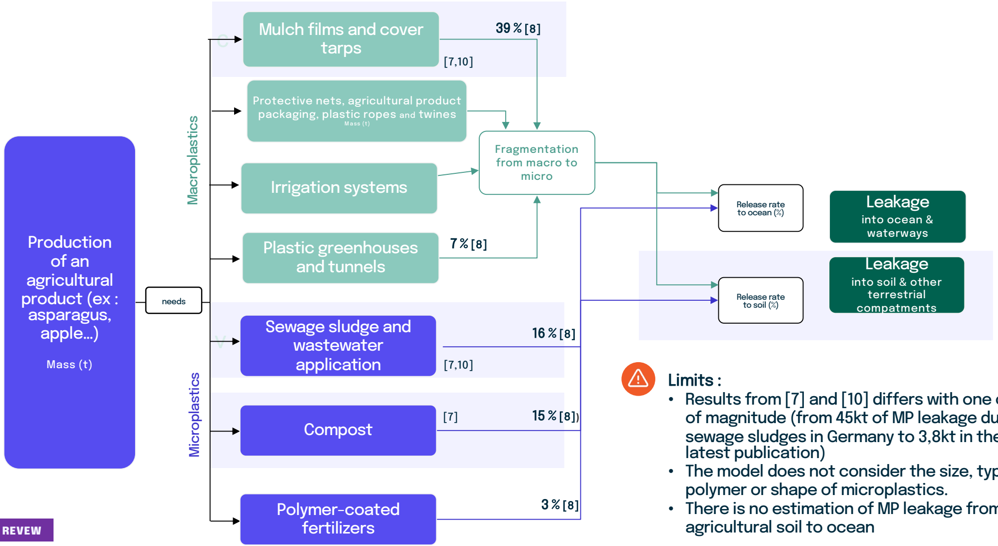
Part. 2

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 for microplastic in agriculture

The path of microplastic leaks for producing an agricultural product - state of the art. The greyed areas indicate what the studies reviewed by PFN cover.



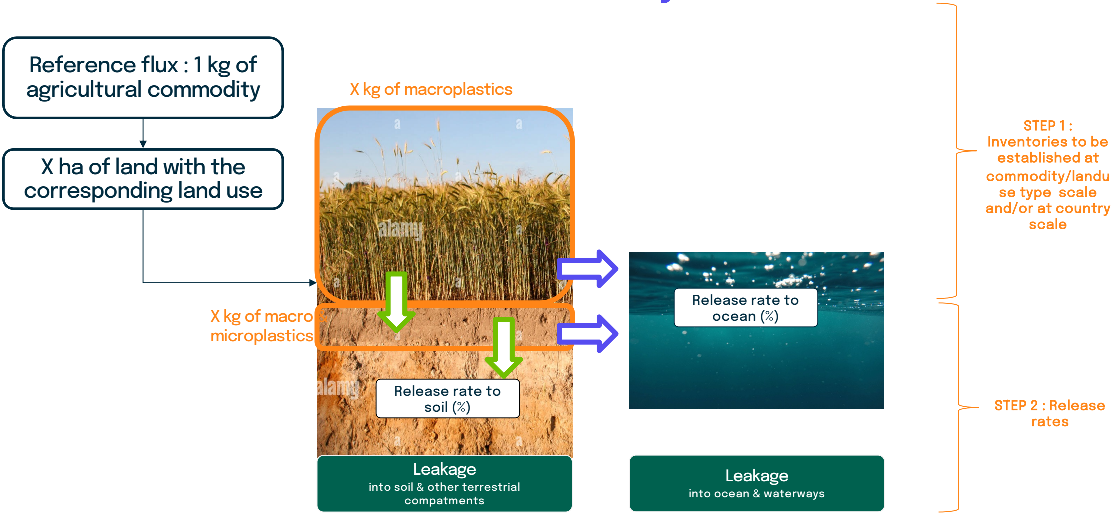
Limits :

- Results from [7] and [10] differs with one order of magnitude (from 45kt of MP leakage due to sewage sludges in Germany to 3,8kt in the latest publication)
- The model does not consider the size, type of polymer or shape of microplastics.
- There is no estimation of MP leakage from agricultural soil to ocean

Preliminary meta analysis on plastic contamination in soils

Article	Source Analysis of Emissions	Impact Analysis	Contamination Quantification	Type of Quantification (Measurement, Estimation)	Geographical Area	Soil type	Practice	Representativity
[7]	/	/	YES	Estimation combining literature data and national/regional statistics on agricultural practices and cropping areas (for all of Germany)	Germany	All agricultural soils	Sewage sludge, composts, and viticulture	Medium, extrapolation from national data
[11]	/	/	YES (review of 23 studies)	Measurement (chemical extraction methods)	China, Chile, Canada, Germany, Australia, Mexico, Sweden, Iran, Spain, Denmark, USA	Mainly agricultural soils	Mainly sewage sludge, but also plastic films, wastewater	Very heterogeneous, punctual site studied, multiple sampling, soil depth studied varies from 3 cm to 50 cm
[9]	YES (over the period 1850-2022)	/	YES	Measurement (H2O2 extraction method and fluorescence microscopy counting)	UK	Agricultural experimental soils	Inorganic fertilizer, organic fertilizer, sewage sludge	Very weak, experimental soils with unique practices, no comparative objective between them
[1]	YES (50% of agricultural plastic mass = mulch films)	YES	/	/	Worldwide	Plant agriculture	All	Global
[13]	YES (analysis of plastic fluxes in Swiss agriculture)	YES (review of impacted terrestrial organisms)	YES (table 2)	Estimates based on surveys	Switzerland	Agricultural soils	Numerous (no sewage sludge in Switzerland)	Medium (data from "expert surveys")
[12]	/	/	YES	Estimation (MFA based on measurements from a previous study)	Switzerland	Agricultural, horticultural, and private soils	Organic waste	Good but specific to Switzerland
[10]	/	/	YES (table 2)	Statistical estimation based on 442 samples from 43 articles (372 from China)	Worldwide (mainly China)	Agricultural soils	Sewage sludge, mulch films	Medium, statistics biased by the overrepresentation of China
[15]	/	/	YES (table 2)	Measurement of MP content in UK sewage sludge combined with results from 5 other studies and EU Commission/Eurostats data on sludge use in European countries	Europe	Agricultural soils	Sewage sludge	Good, based on a calculation method and multiple study data to derive differentiated figures for European countries
[16]	/	/	YES (figure 1)	Estimation based on 3 studies on MP sources and national data	/	Agricultural soils	Sewage sludge	Weak, difficult to date, yet to be compared with Lofty data
[8]	YES (the two main sources appear to be mulch films and sewage sludge)	/	YES (table 1)	Review of studies with measurements	Hungary, China, Japan, Thailand, India, Korea, Switzerland, Germany, Greece, Spain, Netherlands, Tanzania, Mauritius, Tunisia, Chile, Canada, Mexico	Agricultural soils in general	Mulch films, sewage sludge, coated fertilizers, compost, greenhouses, mix	Many heterogeneous data, certain practices are less followed, geographical differences, data in particles/kg of soil and mg of plastic per kg of soil
[18]	N/A	YES	N/A	N/A	N/A	N/A	N/A	N/A
[19]	N/A	YES	N/A	N/A	N/A	N/A	N/A	N/A

Calculation route and secondary dataset



Reduction of plastic release allowed by practice changes (quality of agricultural inputs, macro plastics management) may be addressed in a second phase

Part 3.

Outlook

Future research and methodology developments

Conclusions

Sewage sludges, compost and plastic covers appear to be the main 3 source of MP leakage to soils [8]

No data was found to estimate MP leakage from agricultural to ocean

There is one publication presenting models to estimation MP leakage to soil from sewage sludges, compost and plastic covers, but this model do not include size, type of polymer or shape of microplastics [7]

Estimation of soil PM contamination based on these models remains uncertain [10]

MP behavior in soil remains relatively unknown in term of temporal [9] and spatial [10] dynamics

There is more and more measure of PM soil contamination but the diversity of measure techniques, level of detail and the representativeness of measurements sites limit the ability to perform meta-analysis [11]

Proposal for 2025 objectives

1. Investigating publications using MFA to relate MP leakage sources to MP contamination in crop soils [11,12]
2. Applying existing models to a case study, see methodology developed in [13]. Include macro-plastic leakage?
3. Investigating soil MP contamination data availability at country / world scale by targeted interviews
4. Discussing (again) with the impact working group on how to deal with the impact of plastic leakage from agriculture to soils and oceans

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Plastic Footprint Network

convened by EA – Earth Action

This working group was led by:

earth action & evea

Scientific Committee:

Anthesis
CIRAIG
SYSTEMIQ
MarILCA MARINE IMPACTS IN LCA
Quantis
POLYTECHNIQUE MONTRÉAL UNIVERSITÉ D'INGÉNIERIE
south pole The Climate Company
earth action
WWF

The impact of microplastic leakage module uses the scientific work done by the Earth Action and Evea

The content of the module was developed by:

Aurélie Perrin	EVEA
Martin Chatelain	EVEA
Melissa Gomis	EA

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.

Contact us at: contact@plasticfootprint.earth



Illustrations by German Kopytkov

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