Review of plastic footprint methodologies

Laying the foundation for the development of a standardised plastic footprint measurement tool

Julien Boucher, Carole Dubois, Anna Kounina, Philippe Puydarrieux

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Authors Julien Boucher, Ph.D.
EA – Shaping Environmental Action & University of Applied Sciences and Arts Western Switzerland // HES-SO, HEIG-VD, Yverdon-les-Bains, Switzerland

Carole Dubois
Quantis International, Lausanne, Switzerland

Anna Kounina, Ph.D.
Quantis International, Lausanne, Switzerland

Carole Dubois
Quantis International, Lausanne, Switzerland

Philippe Puydarrieux
IUCN, Economic Knowledge Unit, Lead Natural Resource Economist, Gland, Switzerland

Editors Lea Dubois (lea.dubois@iucn.org) Publication Coordinator
Carole Martinez (carole.martinez@iucn.org)
Gerard Bos (gerard.bos@iucn.org)

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Available from: IUCN (International Union for Conservation of Nature)
Global Marine and Polar Programme (GMPP)
Rue Mauverney 28
1196 Gland
Switzerland
Tel +41 22 999 0000
Fax +41 22 999 0002
marine@iucn.org
www.iucn.org/resources/publications

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Foreword

Our planet is drowning in plastic. Every year, an estimated 8,300 million tonnes of plastic are produced, and up to 12 million tonnes – the equivalent of more than one dump truck per minute – are discarded into our oceans annually. This reflects an imminent global plastic pollution crisis that will require a fundamental paradigm shift in the way we produce, use, and manage plastic. There is currently no common agreed-upon methodology to measure the extent of the plastic pollution crisis. This undermines effective and informed decision-making to successfully tackle the issue. Recognising the needs identified in the UNEA-3 resolution, this review of plastic footprint methodologies lays the foundation for the development of a standardised plastic footprint measurement tool. It also provides, for the first time, an extensive overview of all the existing plastic footprint methodologies – there are currently 19 such methodologies – along with a glossary of key terms related to plastics.

Plastic is versatile, malleable, light weight and cheap. This makes it a tremendously useful material for a wide variety of applications, from plastic bags given at convenience stores and supermarkets, to high-end, space-grade equipment. That being said, plastic's durability – the culprit of its attractive yet problematic attributes – has made it an aggressive pollutant. It is systematically contaminating every corner of our ecosphere and at an alarming pace, infecting the air we breathe, the soil we live on, and the fish we eat. A stark symbol of our economic era, the plastic management crisis has now inspired a powerful momentum in global efforts to stem the tide of this out-of-control pollution problem. It is also fueling an ongoing debate on how best to solve the problem before its magnitude surpasses us.

This publication is part of IUCN's *Close the Plastic Tap* Programme and provides a review of existing methodologies to identify the abundance and distribution, types and sources, as well as pathways and sinks of plastic pollution at different scales. According to this report, what is currently lacking is a standardised methodology to appropriately assess how much plastic is leaking into oceans and to measure how harmful this leakage is for ecosystems and human health. The report finds that most existing methodologies focus on assessment of plastic usage, waste or recycling rates. While many methodologies are being developed, there is currently no methodology for assessing impacts in a comprehensive manner that allows measurement of trade-offs between different impact categories – for example related to climate and ecosystem damage. The report also underlines the critical need to adopt a holistic, all-encompassing approach to measuring the impact of plastic pollution, one that assesses the entire value chain of plastic products and their entire life cycle.

This report's conclusions lay a solid foundation for the development of a standardised and replicable plastic environmental footprint measurement tool. It provides useful recommendations for the development of a standard set of indicators that highlight the costs of inaction, and that help identify investment opportunities into a circular plastic economy. This will in turn drive informed action to tackle plastic at source, thrust efforts towards designing more effective models that will help us assess macro and micro plastic leakages, and provide us with improved data collection and analysis on plastic waste management at the global, regional and national levels.

Minna Epps,
Director, IUCN Global Marine and Polar Programme

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Executive summary

Context

Of the 8,300 million tonnes (Mt) of plastic produced from 1950 to 2015, only 7% has been recycled while more than half has been discarded in landfill or leaked into the environment. Plastic leakage into the environment demonstrates a systemic failure of the take-make-dispose consumption model and makes clear the need for a shift towards more circular material flows. With 10 Mt of plastics leaking into the ocean annually (Boucher & Friot, 2017) from a variety of sources, improving the circularity of plastic flows, from source-to-sea is key.

Companies, organisations, and governments are taking measures to tackle plastic pollution. However, as recognised during the Third United Nations Environment Assembly (UNEA-3, Nairobi, 2017), there is currently no standard methodology to measure the extent of the plastic problem. Countries and other stakeholders were encouraged to "cooperate to establish common definitions and harmonized standards and methodologies for the measurement and monitoring of marine litter and microplastics". Only if equipped with credible, salient and legitimate data and analyses can decision-makers understand their current status, set targets, agree and implement actions, and track progress towards targets over time.

Aims

Recognising the needs identified in the UNEA-3 resolution, this report provides a review of existing and emerging methodologies to identify the abundance, distribution, types, sources, pathways and sinks of plastic pollution at different scales. It also provides an overview of the state of knowledge for impact assessment and monetary valuation methodologies, along with a glossary of key terms related to plastics, marine plastics and environmental footprints.

The review of methodologies covers 19 that had been identified as of early 2019. An analysis reveals two groups of methodologies: the first comprises those that identify plastic waste streams and recycling rates at the national or business level; the second comprises methodologies that focus on pathway modelling to measure plastic leakage into waterways and oceans, from either mismanaged waste or in the form of microplastics. An analysis of the review concludes that there could be stronger convergence between methodologies in this fast-developing area and that plastic footprint methodologies are lacking in several ways.

> ***Current LCAs (Life Cycle Assessment) do not account for plastic as a pollutant. LCAs assume 100% collection of waste streams go to landfill, incineration or recycling.***

Key findings

1. Existing methodologies focus on assessment of plastic usage, waste or recycling rates, with little focus on circularity. Life Cycle Assessment (LCA) and circularity should be used synergistically to identify the best scenarios in terms of reducing environmental impacts while aiming to maximise circularity. Furthermore, stakeholders should be encouraged to use metrics based on leakage/inventory rather than using only recycling rates.

2. While several projects are aiming to develop an inventory approach to assess leakage for both macroplastics and microplastics, they are not yet available for use. Performing a generic plastic footprint based on such methodologies seems to be achievable in the short term, but significant challenges must be overcome to develop a more specific methodology that could support eco-design strategies.

3. There is an acute lack of data to allow for impact assessment and to embed plastic impacts within LCA frameworks. Plastic footprints currently in development propose to include fate in their calculations to account for different residence times or biodegradability rates for different plastics.

The move towards a single indicator, such as a monetary valuation metric, could help weigh the cost of inaction on plastic waste and leakage with other potential actions. Such an approach would not only provide monetary information on the impacts caused by plastic leakage but also on the return on investment of mitigation and remediation measures.

Based on the key findings of this report, IUCN is working in collaboration with UN Environment and the scientific community to develop a best-in-class plastic hotspot methodology that can provide key stakeholders with data and analysis needed to inform their decision-making on reducing plastic leakage.

Category	Name of Methodology	Organisation	Link	Short name	Include microplastics	Date of release
Corporate / Product	Plastic Scan	Searious Business	http://oceanimpact-quickscan.azurewebsites.net	Plastic scan	NO	2017
Corporate / Product	Plastic Disclosure Project (PDP)	Ocean Recovery Alliance	http://plasticdisclosure.org	PDP	NO	2016
Corporate / Product	Plastic Footprint for Companies	Plastic Soup Foundation	https://www.plasticsoupfoundation.org/en/psf-in-action/plastic-footprint-3/	PSF footprint	YES	2017
Corporate / Product	Plastic Scorecard	BizNGO	https://www.bizngo.org/sustainable-materials/plastics-scorecard	Plastic Scorecard	NO	2014
Corporate / Product	Marine Plastic Footprint	IUCN / EA	n.a.	Marine Plastic Footprint	YES	n.a. 2019
Corporate / Product	Plastic Leak Project	Quantis / EA	https://quantis-intl.com/metrics/initiatives/plastic-leak-project/	Plastic Leak Project	YES	n.a. 2019
Corporate / Product	Circularity Indicators Methodology	EMF	https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators	Circularity index	NO	2015
Corporate / Product	Plastic Drawdown	Common Seas	https://www.commonseas.com/projects/plastic-drawdown	Plastic Drawdown	YES	2019
Corporate / Product	Marine Impacts in LCA	CIRAIG / PUCP / NTNU	n.a.	MariLCA	YES	n.a.
Corporate / Product	PlastikBudget	Fraunhofer Institute	n.a.	Plastikbudget	YES	n.a. 2020
Corporate / Product	Plastic Pollution Calculator	ISWA	n.a.	Plastic Pollution Calculator	NO	n.a. 2019
Corporate / Product	PET Collection, Landfill and Environmental Leakage Rates in South East Asia	GA Circular/companies	https://www.gacircular.com/publications/	PET GA PET Collection	NO	n.a. 2019
Corporate / Product	Plastic Life Cycle Assessment (LCA)	JRC	https://eplca.jrc.ec.europa.eu/permalink/plastic lci/plastic lca report/2018.11.20.pdf	LCA	YES	n.a. 2020
Countries / Regions	PiPro SEA	EMF / Companies	n.a.	Project SEA	NO	2019
Countries / Regions	National Guidance For Marine Plastic Hotspotting and Shaping Action	UN Environment / IUCN	n.a.	Hotspot + Action	YES	n.a. 2019
Countries / Regions	A Global Roadmap to Achieve Near-zero Ocean Plastic Leakage	SYSTEMIQ / PEW	n.a.	SYSTEMIQ Roadmap	YES	n.a. 2019
Individuals	Plastic Footprinter	R4W	http://www.plasticfootprint.ch	R4W	NO	2014
Individuals	My Little Plastic Footprint	PSF	http://mylittleplasticfootprint.org	MyLittle Plastic Footprint	YES	2017
Individuals	Plastic Calculator	Greenpeace	http://secure.greenpeace.org.uk/page/conte	Greenpeace	NO	2016

Include the microplastic component

1. Introduction

The alarm has sounded on plastic pollution. Newsfeeds are filled with images of oceans, marine life and coastlines suffocated by plastics. Public awareness has increased dramatically over the last few years and public and private initiatives at international, regional, national, and local levels have emerged to tackle plastic pollution from different entry points.

Policy fixes such as banning plastic straws, taxing plastic bags and discouraging single use items are being implemented all over the world. These important measures do not, however, address the root causes of the issue. Plastic pollution does not always happen at a product's end-of-life. Plastic leakage can also happen earlier in the plastic life cycle, e.g. during the production or transportation phases. To inform operational and policy decisions on the most effective actions to reduce plastic impacts, and to determine the impact of alternative options, decision makers should be provided with reliable information and the necessary tools.

To date there is no common methodology to either measure (through field studies) or assess (through modelling) plastic flow for a country or an industry. In addition, the language and definitions related to plastic footprints are not aligned across the modelling, field and business communities.

Based on the principle that "you cannot manage what you cannot measure", metrics are required to assess the benefits and drawbacks of plastics from an environmental and economic perspective.

The present report aims to:

- provide a review of existing and emerging plastic footprint methodologies;
- provide insights on the state of knowledge on impact assessment methodologies and monetary valuation, as these have been identified as key elements to drive actions that are today rarely included in plastic footprint methodologies;
- provide a glossary of key terms and definitions related to plastics, marine plastics and environmental footprints.

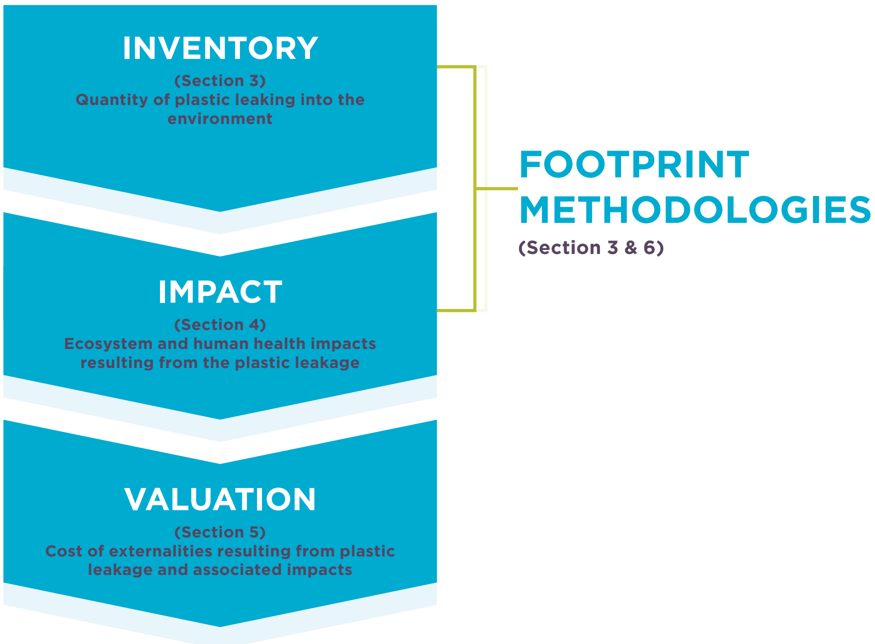


Figure 1. Conceptual model for footprinting methodologies guiding the outline of the report.

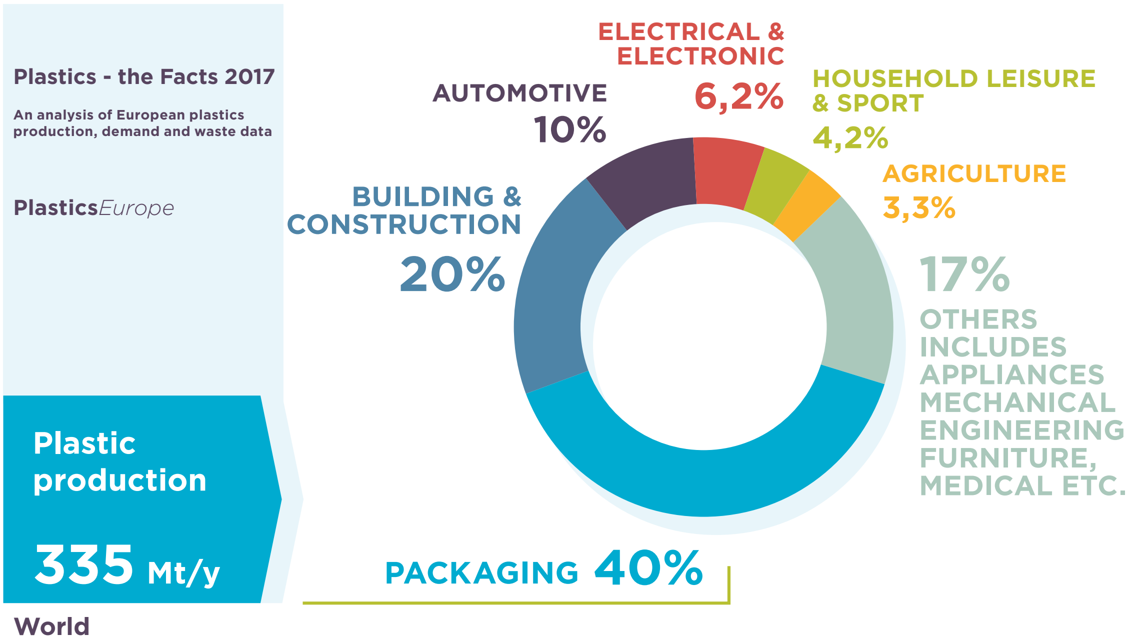


Figure 2. Worldwide plastic production in 2017, share by sector (PlasticsEurope, 2017).

The report is based on a desktop study complemented by discussions with experts. It follows the structure shown in Figure 1.

Inventory methodologies are required to assess the quantities of plastics used, wasted and leaked into the environment, an essential first stage in calculating a plastic footprint. Chapter 2 of this report introduces two complementary approaches used by such methodologies, Life Cycle Analysis (LCA) and Environmentally Extended Input-Output Analysis (EEIOA). A review of existing inventory methodologies, and some that are in development, is provided in Chapter 3.

Assessment of impacts, such as on ecosystems and/or human health, resulting from plastic leakage is a second stage in calculating a plastic footprint. State of the art methodologies for plastic

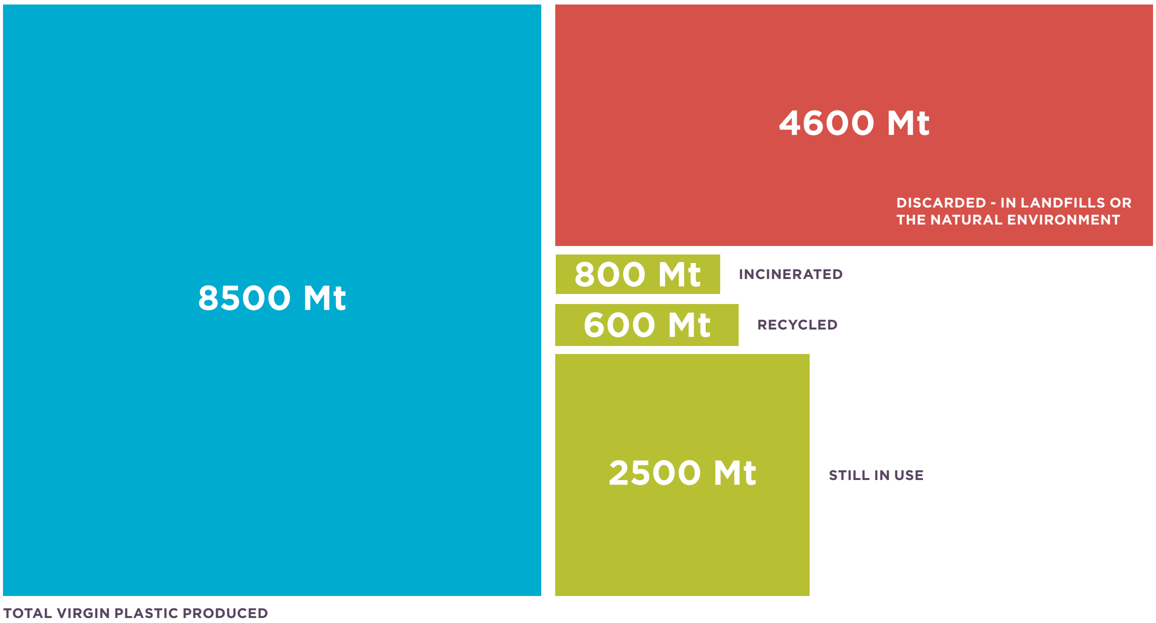


Figure 3. Plastic production and fate from 1950 to 2015 (adapted from Geyer et al., 2017).

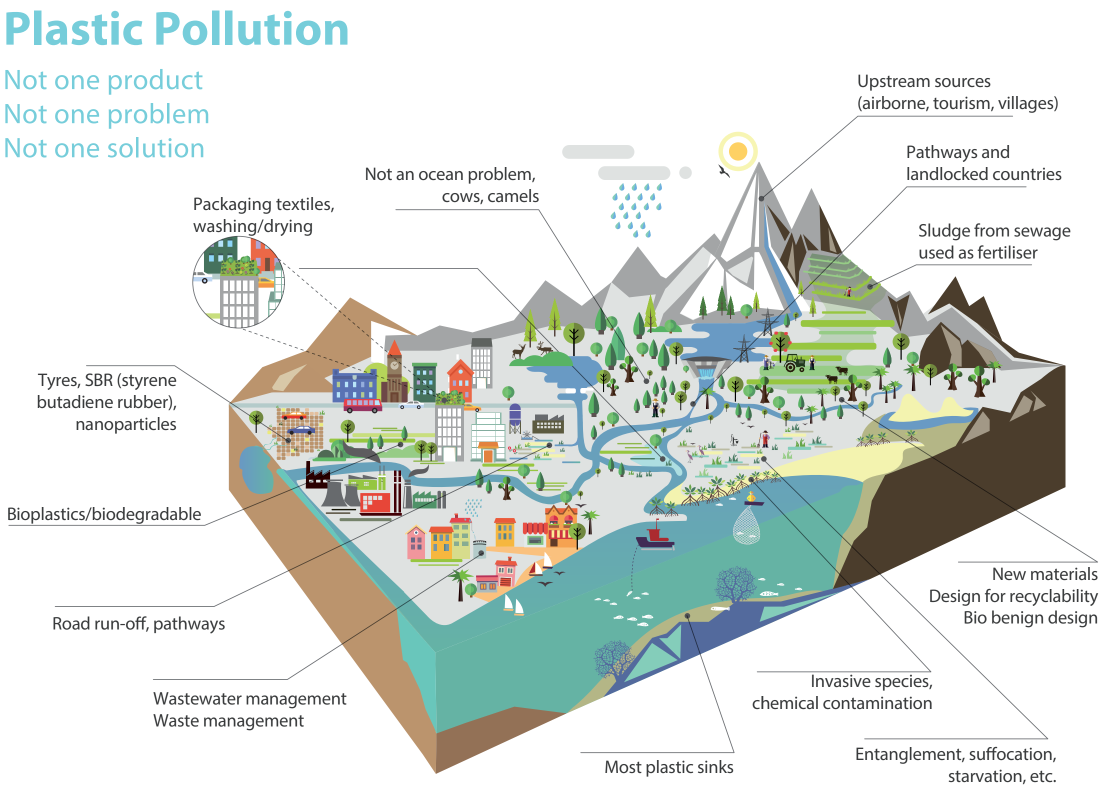


Figure 4: Plastic leakage from source-to-sea (adapted from the IUCN Water 'Natural Infrastructure for Water Management' infographic)

impact assessment are presented in Chapter 4. Valuation enables the monetization of externalities and provides one single indicator in monetary value. Insights on monetary valuation and its applicability for marine plastic pollution are provided in Chapter 5. Finally, Chapter 6 provides a gap analysis and recommendations on how to further develop plastic footprint methodologies.

1.1. Increasing plastic production

The production, use, waste and leakage of plastics has a range of human health, socio-economic and environmental impacts. The evidence base on the scope and scale of current impacts is growing. The predicted rise in global plastic production in the next 30 years could exacerbate those impacts or contribute to new impacts. The versatility, durability, malleability, light weight and low cost of plastic provides many benefits to society (Figure 2). For many applications, plastics can offer lower carbon footprint alternatives than comparable materials (e.g. light plastic packaging *versus* heavier glass packaging) (FOEEUROPE, 2018).

Since the beginning of the plastic production era, 8,300 million tonnes (Mt) of plastics have been produced and only 7% has been recycled (1950-2015) (Geyer et al., 2017). A large proportion, 4,600 Mt, has been discarded, entering landfill or leaking into the environment (Figure 3). This steady leakage of plastic into the ocean owing to lack of management is causing pressing environmental issues.

1.2. Pervasive plastic leakage causing negative environmental impacts

Plastics enter the ocean and soils from various sources and via various pathways. Two main categories can be identified: the visible macroplastics resulting from mismanagement of waste disposal, and the mostly invisible microplastics released from various sources as a result of their use.

Every day, around 27,000 tonnes of plastics leak into the ocean. That is equivalent to almost 10 million tonnes per year (Boucher & Friot, 2017), a quantity that is expected to double in the next

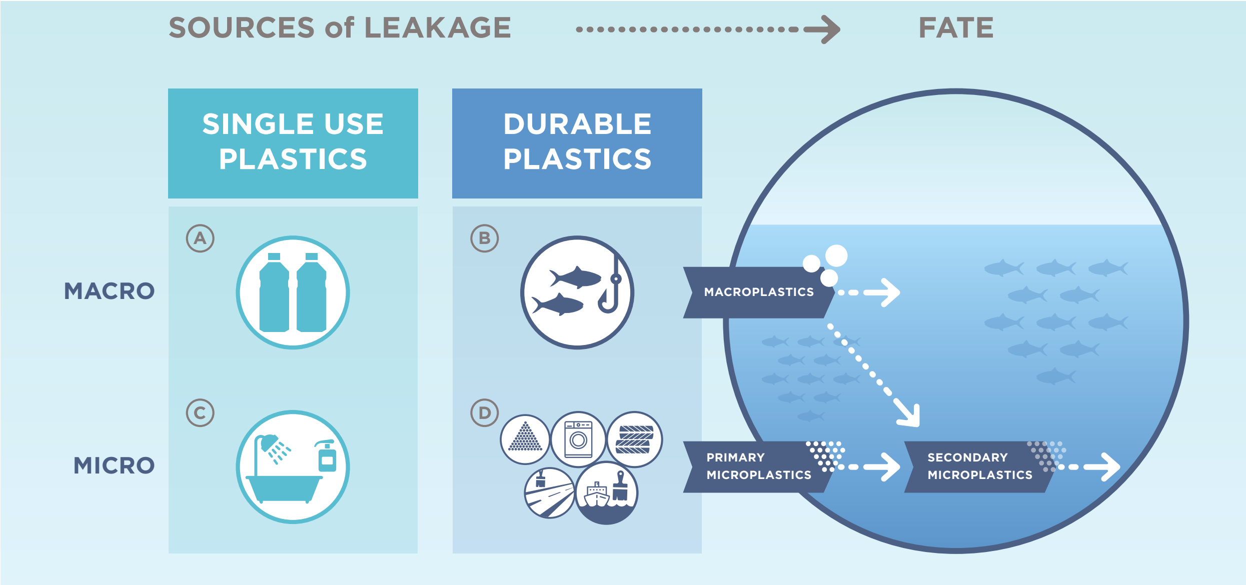


Figure 5: Microplastic and macroplastic leakage from different sources (source: Boucher et al., forthcoming).

decade if no action is taken (Geyer et al., 2017; Jambeck et al., 2015). Plastic leakage comes with a cost: the total natural capital cost of plastics in the consumer goods industry has been estimated at US$ 75 billion, of which US$ 40 billion was related to plastic packaging, exceeding the profit pool of the plastic packaging industry (UNEP, 2014).

The scale of leakage of these different types of plastics depends on the geographical context: leakage of macroplastics from mismanaged waste disposal is dominant in coastal countries, especially countries with poor waste treatment facilities (Jambeck et al., 2015).

In contrast, microplastics are a much more pervasive issue with more subtle routes of leakage to the ocean than macroplastics, for example from cosmetics use or washing synthetic clothes, or from tyre and road wear particles (Boucher & Friot, 2017). Released through household waste water or road run-off, microplastics can pass through treatment systems and end up in rivers and oceans with various negative effects on ecosystems and potentially human health (Figure 5).

The current environmental problem is related to the magnitude of the leakage of plastics and potentially toxic chemical additives into the environment during production, transport, use and disposal management.

1.3. The need for better metrics and data

Plastic leakage into the environment demonstrates a systemic failure of the take-make-dispose consumption model and makes clear the need for a shift towards more circular material flows. Improving the circularity of plastic flows is key in this regard, but not the sole component of the solution.

To provide a clear picture of the impacts of and opportunities related to plastic usage, and to make informed decisions, reliable metrics are necessary. This is not only to measure and understand plastic leakage along the value chain, but also to avoid a situation where efforts to mitigate the impacts of plastic leakage lead to more severe environmental problems caused by alternative approaches. This requires impact assessment methodologies and gathering better data on the fate and effects of plastics both on ecosystems and human health.

A commonly accepted and understood methodology for calculating a plastic footprint would provide the clarity required by policymakers and stakeholders, across the plastics value chain, to take informed actions to reduce plastic leakage. Environmental footprints typically consist of a measure of all emissions or pollutants, whether direct or indirect, associated with the entire life cycle of a product or service. For a plastic footprint, plastic leakage is measured. Two methodologies to undertake such measurement are covered in the present report: Life Cycle Assessment (LCA) and Environmentally Extended Input-Output Analysis (EEIOA). The inventory of leakage developed by these methodologies can be complemented by an assessment of the impacts of that leakage and a monetary valuation of those impacts.

Several studies have inventoried and quantified different sources of plastic leakage either nationally (e.g. Essel et al., 2015; Lassen et al., 2015; Magnuson et al., 2016; Sundt et al., 2014), internationally (e.g. Boucher & Friot, 2017; EUNOMIA, 2016; Jambeck et al., 2015), or from rivers (e.g. Lebreton et al., 2017). These pioneer studies identified plastic leakage at the global level, ranging from 8 to 12.2 Mt depending on the methodology, model and data used.

When existing LCAs consider waste management scenarios, they ignore environmental leakage of packaging. In a recent review of 31 LCA studies, Schweitzer et al. (2018) demonstrated that none of the studies attempted to take inappropriate disposal into account. This means that current LCAs assume 100% collection of waste streams which go to landfill, incineration or recycling. In reality this is not the case and a substantial proportion of microplastics and macroplastics end up in the environment through leakage.

The need for harmonised standards and methods is acute. The scientific LCA community acknowledges that the impacts generated by marine debris (macroplastics and microplastics) are not adequately addressed in LCA (Woods et al., 2016). Woods et al. (2016) provided a comprehensive overview of data gaps in Life Cycle Impact Assessment (LCIA) on the pathways leading to marine biodiversity loss. The quantitative approaches for the environmental assessment of seven major drivers of marine biodiversity loss have been reviewed, i.e. climate change, ocean acidification, eutrophication-induced hypoxia, seabed damage, invasive species, over-exploitation, and marine plastic debris. The authors' conclusion on the marine plastic debris approach coverage is that "No methods for quantifying the effect of plastic waste on biodiversity at scales greater than individual organisms have yet been proposed". The direct consequence of this lack of an assessment method is that the question of whether plastics constitute the current biggest threat to the ocean remains unresolved.

Input – Output models

Input–output model is a quantitative economic technique that represents the interdependencies between different branches of a national economy or different regional economies. From data on financial exchanges, knowledge on physical flows such as consumption of raw materials can be extrapolated.

Sustainability practitioners also convey a strong signal on the existence of data gaps. In a recent survey of 52 companies (see Appendix 1), 80% of respondents said that they lack appropriate methodology and supporting data to assess plastic leakage and support decisions for eco-design or plastic stewardship.

Better metrics are required in three broad areas, as detailed in sections 3, 4 and 5 of the present report:

- Metrics to inventory plastics leaking into the environment: "How much plastic is leaking and from where?"
- Metrics to assess environmental impacts resulting from this leakage: "What are the environmental impacts resulting from plastic pollution?"
- Metrics to apply monetary valuation to the consequences of the leakage and environmental impacts: "How do the environmental impacts of plastic rank with regard to other environmental issues?"

2. Plastic footprint methodologies

This chapter aims to define an environmental footprint and understand the objectives associated with different footprint methodologies.

In general, environmental footprint methodologies are used for different purposes, such as:

1. decision support for product design or at the strategic level,
2. monitoring and guiding actions at a more operational level,
3. disclosing or reporting a level of performance, and
4. communicating to clients and supporting marketing campaigns.

2.1. What is an environmental footprint?

Footprint methodologies can be applied to individuals, companies, countries, regions or globally.

Marques et al. (2017) use the term footprint to refer to "metrics that capture the direct effects of an activity as well as the indirect effects that are transferred along a supply chain". For Fang et al. (2016), "there is no 'universal' footprint definition that would be sufficient for all purposes".

To ease the understanding of the concept and help experts design a specific methodology according to specific objectives, Fang et al. (2016) suggest a classification scheme of the whole footprint family, captured in Figure 6, where each

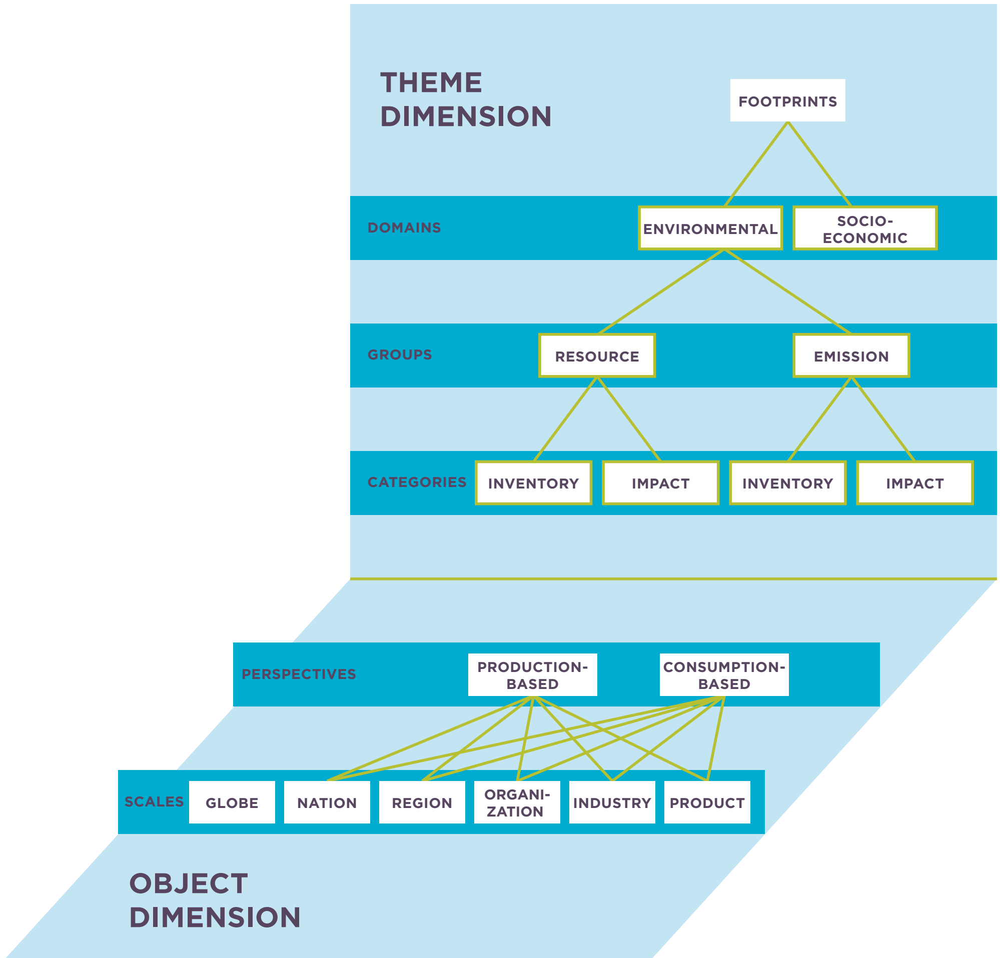


Figure 6: Scheme for classifying the whole footprint family (source: Fang et al., 2016).

footprint has a theme dimension and an object dimension. According to Fang et al. (2016) the object dimension describes the scale of the analysis (e.g. global, national, sectoral, or products) meanwhile the theme dimension describes the topic that is assessed (e.g. carbon, water, or plastics).

The theme dimension distinguishes environmental footprints from socio-economic footprints. Environmental footprints can then be divided into two categories:

1. **Resource-based** footprints measure the flow of inputs to human activities.

2. **Emission-based** footprints focus on the flow of outputs from human activities.

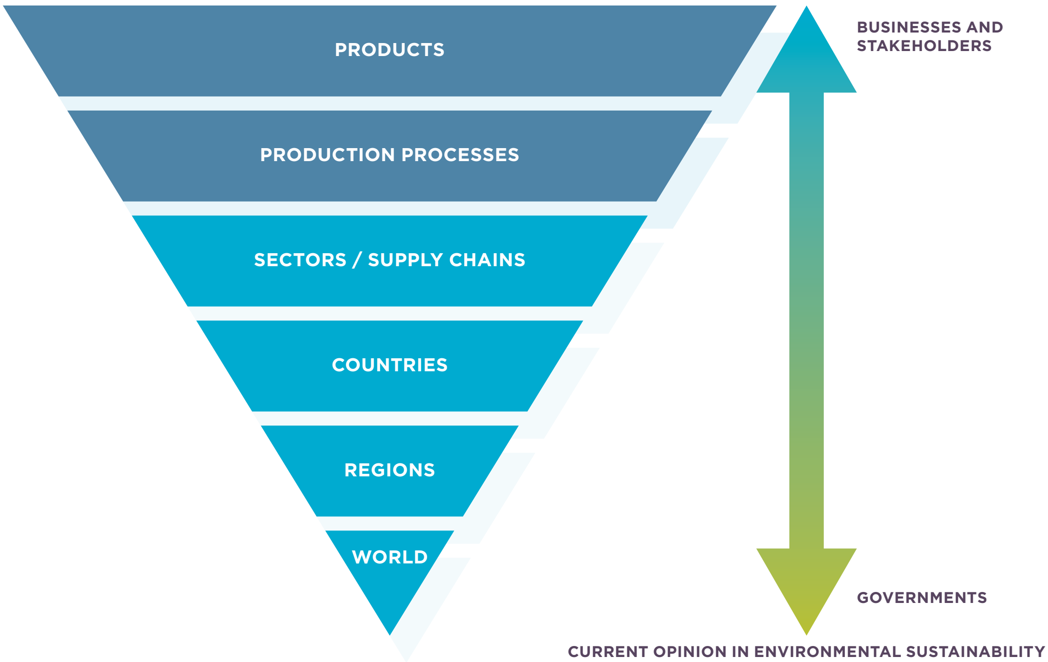
The domain or the themes that are monitored usually qualify the footprint: carbon footprint, ecological footprint, water footprint, biodiversity footprint or plastic footprint. Socio-economic footprints focus on social dimensions such as the employment footprint, the labour footprint, or the inequality footprint.

Within the object dimension a differentiation can be made between consumption-based and production-based footprints:

- Production-based footprints aim to measure a certain type of pressure associated with a given production, whether it is consumed locally or exported. These often relate to accounting and inventories.

- Consumption-based footprints account for all the upstream impacts (also called consumption-based impacts) that are required for a given final consumption, i.e. impacts of domestic production and imports. These footprints can be applied at the individual, national, business or products level.

The different footprints can be quantified both through EEIOA and LCA methods. But generally, product footprints are subject to bottom-up LCA, while national footprints are subject to top-down EEIOA, as highlighted in Figure 7. When targeting an intermediate scale both types can be mobilised through a hybrid approach.



LEVELS OF APPLICATION OF LCA (DARK BLUE AREAS OF THE PYRAMID) AND EMRIO (LIGHT BLUE AREAS OF THE PYRAMID) AND MAIN INTEREST OF ACTORS. THE ARROW REPRESENTS THE LEVEL OF INTEREST SPANNING FORM GOVERNMENTS (GREEN) TO BUSINESSES AND OTHER STAKEHOLDERS (BLUE). THE POSITION IN THE PYRAMID OF THE DIFFERENT LEVELS OF APPLICATION REPRESENTS THE NUMBER OF ACTORS ASSOCIATED WITH EACH.

Figure 7: Levels of application of LCA and EEIOA.

LCA is usually applied to measure footprints of products and production processes, while EEIOA is used to assess footprints at global or national level. Hybrid methods mobilising both LCA and EEIOA can be used in intermediate cases such as to assess sectoral footprints. LCA is applied more often than EEIOA, showing the high level of interest in LCA, especially in businesses. This is why most of the methodologies presented in this report are related to LCA. However, even though they are less numerous, applications of EEIOA at global and national level can have a very strong impact to support policymaking. For instance, EEIOA was used to enlighten the debate on the accountability of countries with respect to their carbon emissions (Marques et al., 2017).

Footprint measurement through a consumption-based approach has the benefit of measuring both local *and* exported impacts associated with a given final demand. Such an approach can effectively document, on an individual or collective level, direct and indirect responsibility vis-à-vis key environmental issues. For example, it may be that production generates a very small footprint in a given country, with national demand satisfied by externalising production in other countries. In such a case, the consumption footprint of the country will be higher than its production footprint.

A national net footprint is the footprint of a country minus the pollution that is emitted within the country's borders that belongs to other nations' footprints. Some countries are net exporters of environmental impacts while others are net importers. Developed countries often have positive net footprints, while developing countries often have negative net footprints.

A national plastic footprint consists of the sum of domestic plastic pollution that serves domestic consumption and foreign plastic pollution that serves consumption in that particular country.

For example, a given country can import products whose production generates deforestation in other countries. Importing such goods is like importing deforestation. In this case, this country is a net importer of deforestation and so has a positive net footprint regarding the topic of deforestation.

In many cases, environmental footprints are not limited to measuring flows of pollutants but also account for the resulting environmental impacts, which can be defined as the aggregation of the various effects caused by different pollutants with respect to a given environmental issue. For example, carbon footprints account for the environmental impacts of various emissions (CO_2, methane, N_2O, CFC, etc.) expressed in CO_2 equivalent. An impact assessment framework for plastic is suggested in Chapter 4.

2.2. What are plastic footprint methodologies?

A broad range of footprint methodologies have been developed in the past two decades to inform the public, companies and policymakers about the magnitude of consumption and production activities affecting the environment.

This report takes a wide definition of what is included in a footprint, considering all methodologies (existing and under development) that assess the environmental performance of the plastic usage within a system (industry, company, product or country).

As illustrated in Figure 8, the notion of footprint may include three dimensions, leading to the following different types of metric:

1. The **quantity of plastic used in a system** (often referred to as the "source"). Here the plastic footprint is expressed in kilograms of plastics per year.

2. The **quantity of plastic emitted into the environment during production, transport, use or end-of-life of a plastic product** (often referred to as plastic leakage). Here the plastic footprint represents an inventory, in unit of mass, of plastic leakage into the environment. The quantification of resource

consumption as well as of the pollutants (i.e. the plastic itself and associated toxicants) emitted into the environment throughout the life cycle is referred to as "the inventory" by the LCA community.

3. The **impact, directly or indirectly generated by the pollutants emitted (or the leaked plastic) on human health or the environment**. Impact assessment is a feature of the most advanced footprinting methodologies and requires the definition of one or multiple impact pathways and LCIA methodologies. Impact assessment generally relies on three stages: fate, exposure and effect assessments.

Taking a broad definition of the notion of plastic footprint, the review of methodologies presented in Chapter 3 includes plastic use accounting methodologies, leakage assessment methodologies, chemical toxicity tools, impact assessment methodologies, and material circularity indicators. The methodologies considered may tackle macroplastics and/or primary microplastics. The review is not intended to be exhaustive.

2.2.1. Life Cycle Assessment (LCA)

LCA is an environmental assessment methodology based on an inventory of potential flows of pollutants entering different compartments of the environment (e.g. air, water, soil) and the assessment of associated environmental impacts. LCA methodologies are starting to integrate plastics as a pollutant and mainly deliver inventories, i.e. assessments of the amount of plastics lost throughout a product life cycle.

Plastic footprints based on an LCA methodology are typically applied to a specific product or company. They include a direct and an indirect component.

1. The direct component accounts for material consumption, pollutant emissions and impacts created by the company or product itself, e.g. when packaging is dropped as litter.

2. The indirect component accounts for additional activities related to the company or product at other stages of its life cycle controlled by third parties, e.g. when plastic

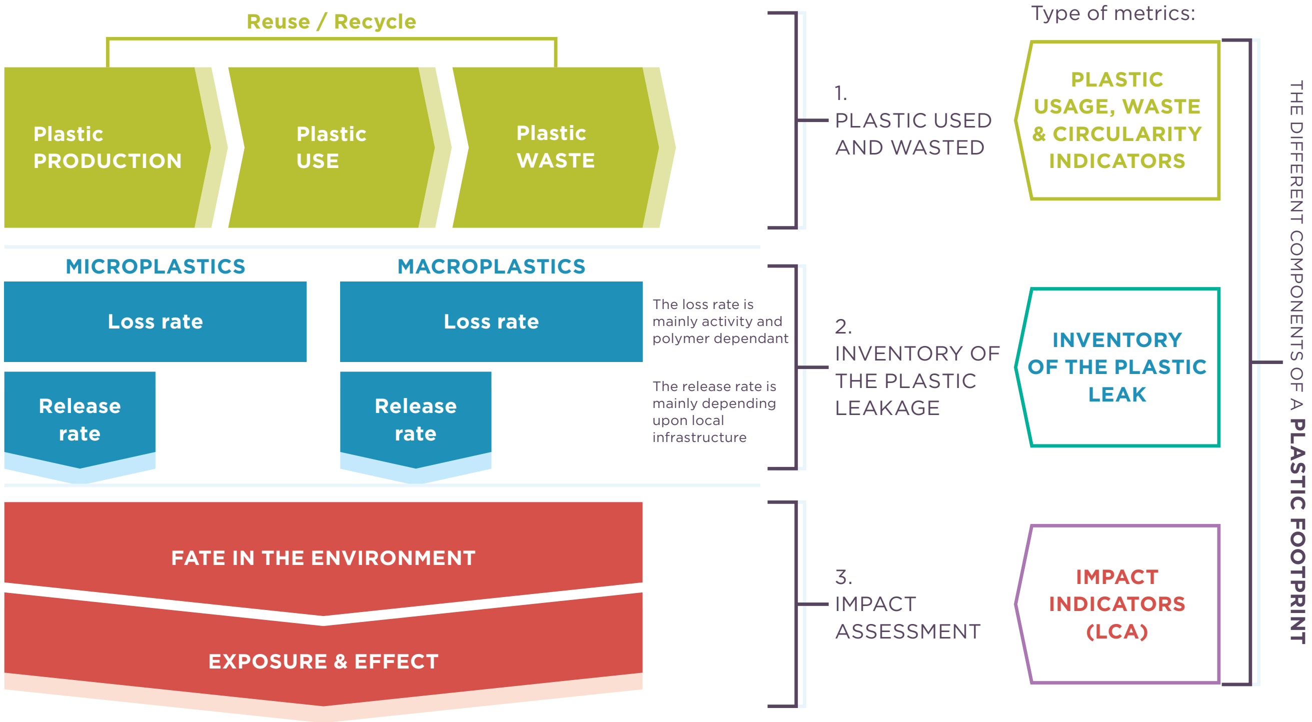


Figure 8. What is included in a plastic footprint? 3 main modeling stages lead to 3 types of metrics : 1) plastic usage, waste and circularity indicators, 2) plastic leakage indicators, and 3) impact indicators.

pellets used for one component of a given plastic product are lost by a sub-contractor.

A plastic footprint using LCA is a predictive methodology based on modelling measurements that compile data on industry and product life cycles, as opposed to a descriptive methodology based on field study measurements that compile data on plastic concentrations collected *in situ*. While the knowledge gathered through descriptive methodologies is very useful to elaborate and validate findings from prescriptive plastic footprint methodologies, the models and data embodied in a predictive methodology can inform decision-making and strategy setting, e.g. when defining new product portfolios and supporting eco-design approaches.

2.2.2. Environmentally Extended Input-Output Analysis (EEIOA)

At global and national levels, the recent development of Multi-Regional Input-Output (MRIO) tables and EEIOA has facilitated the development of various footprints: carbon footprint, water footprint, land footprint, biodiversity footprint. The main feature of these Input-Output (IO) tables is to summarise all financial flows related to international trade. They make it possible to calculate indirect environmental impacts by tracing the distant effects of consumption with a life cycle perspective. In other words, IO models make it possible to include the impacts caused abroad by the production of a given imported good and/or to exclude the impacts of the same good when exported.

EEIOA assesses the impact of traded commodities through upstream supply chains (Wiedmann et al., 2011) and has been applied to the assessment of the indirect drivers of carbon emissions (Pasquier, 2012; Peters et al., 2011; Tukker et al., 2014; Wiebe & Yamano, 2016), water consumption (Hoekstra et al., 2012; Tukker et al., 2014), and land use change (MacDonald et al., 2015; Tukker et al., 2014). Indeed, this method seems promising for applications in the field of biodiversity and has given rise to many academic studies related to global value chains (Chaudhary & Kastner, 2016; Lenzen et al., 2012; Moran & Kanemoto, 2017; Verones et al., 2015, 2017; Wilting et al., 2017).

The EEIOA methodology and the mathematics behind it are summarised in Appendix 3.

EEIOA presents the following characteristics:

A large scale approach

EEIOA can be considered a top-down approach, as the data used are based on national accounts and sectorial analysis. A plastic footprint using IO analysis can be established at global, regional or national levels.

When using an MRIO table, the plastic footprint will depend on the characteristics of the table, in particular the number of countries and products or sectors covered. For example, the fewer the sectors, the less accurate the calculation of the footprint will be.

A geographical approach

In a world where consumption and production are often spatially disconnected, footprint methodologies based on EEIOA make it possible to show how and where the impacts related to the consumption of a specific product are divided and located. With regard to plastic leakage, a national plastic footprint identifies the other countries and regions of the world to which the impacts of domestic consumption are exported. In other words, it allows an understanding of which countries are accountable for the plastic leakage that takes place in a specific country or region. At large scale, EEIOA enables the assessment of the direct and indirect impacts of a given domestic demand.

An integrated approach

Based on MRIO tables, EEIOA reflects the plastic leakage and/or the impacts resulting from plastic leakage embodied in all international trade flows without isolating specific sectors of activities. This disaggregation of a plastic footprint should give information about the contribution of particular economic activities to the total impacts of consumption.

A suitable approach for modelling

As an analysis of the impact of domestic demand, this approach is appropriate for assessing the environmental consequences of changes in demand. These changes can result from the adoption of international trade agreements or new border taxes. Modelling changes in domestic demand coupled with an IO analysis can evaluate the environmental effects of a new trade agreement or other public policy affecting a country's consumption.

3. Review of existing plastic footprint methodologies

This chapter presents a review of existing or under development plastic footprint methodologies. They can be used by individuals, businesses, countries or regions to generate data to guide policymakers towards measures to address plastic leakage.

3.1. Criteria for the selection of the methodologies reviewed

The criteria for the selection of methodologies are that they are either available to use as a tool, i.e. methodological guidance is published, or they are under development. Scientific reports and publications assessing plastic sources and inputs from land to ocean are not reviewed, but some are included in the bibliography.

3.2. Review of plastic footprint methodologies

Nineteen methodologies have been reviewed as summarised in Table 1. These methodologies can be classified in three main categories:

1. Business- or product-level footprint methodologies, intended to be used by the private sector;

2. National- or regional-level footprint methodologies, intended to be used by the public sector; and

3. Individual-level footprint methodologies, intended to be used by citizens and consumers.

The review specifies whether the plastic footprint methodology accounts for microplastics. A factsheet for each methodology includes:

- The full and short name.
- The name of the organization that developed it.
- Its web link.
- A short description.
- An overview of what is and is not included.

Table 1 : Inventory of existing and under-development plastic footprint methodologies.

	Name of Methodology	Organisation	Link	Short name	Include microplastics	Date of release
Corporate / Product	Plastic Scan	Searious Business	http://oceanimpact-quickscan.azurewebsites.net	Plastic scan	NO	2017
	Plastic Disclosure Project (PDP)	Ocean Recovery Alliance	http://plasticdisclosure.org	PDP	NO	2016
	Plastic Footprint for Companies	Plastic Soup Foundation	https://www.plasticsoupfoundation.org/en/psf-in-action/plastic-footprint-3/	PSF footprint	YES	2017
	Plastic Scorecard	BizNGO	https://www.bizngo.org/sustainable-materials/plastics-scorecard	Plastic Scorecard	NO	2014
	Marine Plastic Footprint	IUCN / EA	n.a.	Marine Plastic Footprint	YES	n.a. 2019
	Plastic Leak Project	Quantis / EA	https://quantis-intl.com/metrics/initiatives/plastic-leak-project/	Plastic Leak Project	YES	n.a. 2019
	Circularity Indicators Methodology	EMF	https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators	Circularity index	NO	2015
	Plastic Drawdown	Common Seas	https://www.commonseas.com/projects/plastic-drawdown	Plastic Drawdown	YES	2019
	Marine Impacts in LCA	CIRAIG / PUCP / NTNU	n.a.	MariLCA	YES	n.a.
	PlastikBudget	Fraunhofer Institute	n.a.	Plastikbudget	YES	n.a. 2020
	Plastic Pollution Calculator	ISWA	n.a.	Plastic Pollution Calculator	NO	n.a. 2019
	PET Collection, Landfill and Environmental Leakage Rates in South East Asia	GA Circular/companies	https://www.gacircular.com/publications/	PET GA PET Collection	NO	n.a. 2019
	Plastic Life Cycle Assessment (LCA)	JRC	https://eplca.jrc.ec.europa.eu/permalink/plastic lci/plastic lca report/2018.11.20.pdf	LCA	YES	n.a. 2020
Countries / Regions	PiPro SEA	EMF / Companies	n.a.	Project SEA	NO	2019
	National Guidance For Marine Plastic Hotspotting and Shaping Action	UN Environment / IUCN	n.a.	Hotspot + Action	YES	n.a. 2019
	A Global Roadmap to Achieve Near-zero Ocean Plastic Leakage	SYSTEMIQ / PEW	n.a.	SYSTEMIQ Roadmap	YES	n.a. 2019
Individuals	Plastic Footprinter	R4W	http://www.plasticfootprint.ch	R4W	NO	2014
	My Little Plastic Footprint	PSF	http://mylittleplasticfootprint.org	MyLittle Plastic Footprint	YES	2017
	Plastic Calculator	Greenpeace	http://secure.greenpeace.org.uk/page/conte	Greenpeace	NO	2016

Include the microplastic component

Plastic Scan

Plastic Scan

Searious Business

Method available since 2017

http://oceanimpact-quickscan.azurewebsites.net/

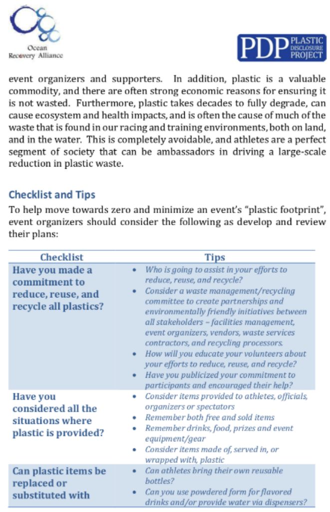
Developed as an online tool by the company Searious Business, the Plastic Scan uses the responses to a 10-question survey to provide the user with an overview of plastic use and waste within their company. Based on the results, the tool attributes a label ranging from A to F, which can then be used for communication and awareness-raising purposes. If the user wants to get further insight on the company's plastic footprint, a more detailed survey is available on request. The latter can be paired with a visit and interviews at the production facility or logistics centre.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage	X	
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific		X
	Country specific		X
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available		X
	Case studies available (related to plastic leakage)		X

Plastic Disclosure Project

Plastic Disclosure Project	**Plastic Disclosure Project**
	Ocean Recovery Alliance
	Method available since 2017
	http://plasticdisclosure.org

This tool was developed by the Ocean Recovery Alliance and provides an assessment of plastic flow for manufacturers, service providers and municipalities. By encouraging companies to disclose their plastic use and supporting management strategies to reduce plastic waste and improve waste management, the Plastic Disclosure Project is intended to work as a preventative mechanism. It encourages plastic reduction in a measurable way and highlights leading companies as a means of driving action. Businesses measure their own plastic footprint, draft solutions and disclose reports. Individual companies can choose whether to disclose their own data on plastic use. Investors, governments and NGOs are invited to review and endorse these reports.


Ocean Recovery Alliance

PDP PLASTIC DISCLOSURE PROJECT

event organizers and supporters. In addition, plastic is a valuable commodity, and there are often strong economic reasons for ensuring it is not wasted. Furthermore, plastic takes decades to fully degrade, can cause ecosystem and health impacts, and is often the cause of much of the waste that is found in our racing and training environments, both on land, and in the water. This is completely avoidable, and athletes are a perfect segment of society that can be ambassadors in driving a large-scale reduction in plastic waste.

Checklist and Tips

To help move towards zero and minimize an event's "plastic footprint", event organizers should consider the following as develop and review their plans:

Checklist	Tips
Have you made a commitment to reduce, reuse, and recycle all plastics?	• Who is going to assist in your efforts to reduce, reuse, and recycle? • Consider a waste management/recycling committee to create partnerships and environmentally friendly initiatives between all stakeholders – facilities management, event organizers, vendors, waste services contractors, and recycling processors. • How will you educate your volunteers about your efforts to reduce, reuse, and recycle? • Have you publicized your commitment to participants and encouraged their help?
Have you considered all the situations where plastic is provided?	• Consider items provided to athletes, officials, organizers or spectators • Remember both free and sold items • Remember drinks, food, prizes and event equipment/gear • Consider items made of, served in, or wrapped with, plastic
Can plastic items be replaced or substituted with	• Can athletes bring their own reusable bottles? • Can you use powdered form for flavored drinks and/or provide water via dispensers?

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage		X
	Environmental impacts (from plastic leakage)		X
	Microplastics		X
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific	X	
	Country specific		X
	Archetype specific (by income level)		X
Description of the tool	Online version	X	
	Labelling/accreditation scheme	X	
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available		X
	Case studies available (related to plastic leakage)	X	

PSF footprint

Plastic Footprint for Companies

Plastic Soup Foundation

Method available since 2017

https://www.plasticsoupfoundation.org/en/psf-in-action/plastic-footprint-3/

The Plastic Footprint is a standardised methodology for companies developed by the Plastic Soup Foundation, Erasmus University Rotterdam and PwC. Based on a survey, the methodology is designed to enable companies to track their plastic use along their supply chain, to help them identify how to reduce plastic use, prevent leakage into the environment and increase plastic reuse. Companies don't just get a better insight into their own use of plastic; they also see how their suppliers and customers deal with plastic. The Plastic Footprint for companies is currently being tested.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage		X
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific	X	
	Country specific		X
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme	X	
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available		X
	Data collection guidance available		X
	Dataset available		X
	Case studies available (related to plastic leakage)		X

Plastics Scorecard

Plastics Scorecard

BizNGO

Method available since 2014

https://www.bizngo.org/sustainable-materials/plastics-scorecard

The Plastics Scorecard was developed by BizNGO with the aim of reducing the number and volume of chemicals of high concern used in manufacturing plastics and in the plastic products themselves. It measures the chemical footprint of plastics by evaluating plastic polymers on a scale ranging from 0 (most hazardous) to 100 (most benign) based on the number and weight percentage of high-concern chemicals contained in plastic products. Scores from A+ to F are given as a means of expressing the footprint. The methodology takes a hazard-based approach, as opposed to a risk-based approach (i.e. not taking into account exposure, bioavailability, etc.).

The Plastics Scorecard also recommends a five-step programme for companies seeking to reduce the chemical footprint of their plastics.

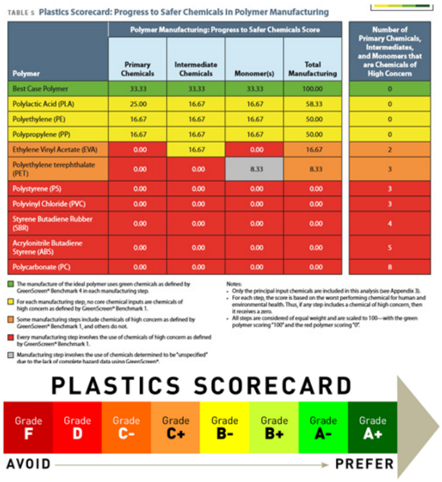


TABLE 5 Plastics Scorecard: Progress to Safer Chemicals in Polymer Manufacturing

Polymer	Polymer Manufacturing: Progress to Safer Chemicals Score				Number of Primary Chemicals, Intermediates, and Monomers that are Chemicals of High Concern
	Primary Chemicals	Intermediate Chemicals	Monomer(s)	Total Manufacturing	
Best Case Polymer	33.33	33.33	33.33	100.00	0
Polylactic Acid (PLA)	25.00	16.67	16.67	58.33	0
Polyethylene (PE)	16.67	16.67	16.67	50.00	0
Polypropylene (PP)	16.67	16.67	16.67	50.00	0
Ethylene Vinyl Acetate (EVA)	0.00	16.67	0.00	16.67	2
Polyethylene terephthalate (PET)	0.00	0.00	8.33	8.33	3
Polystyrene (PS)	0.00	0.00	0.00	0.00	3
Polyvinyl Chloride (PVC)	0.00	0.00	0.00	0.00	3
Styrene Butadiene Rubber (SBR)	0.00	0.00	0.00	0.00	4
Acrylonitrile Butadiene Styrene (ABS)	0.00	0.00	0.00	0.00	5
Polycarbonate (PC)	0.00	0.00	0.00	0.00	8

- The manufacture of the ideal polymer uses green chemicals as defined by GreenScreen® Benchmark 4 in each manufacturing step.
- For each manufacturing step, no core chemical inputs are chemicals of high concern as defined by GreenScreen® Benchmark 1.
- Some manufacturing steps include chemicals of high concern as defined by GreenScreen® Benchmark 1, and others do not.
- Every manufacturing step involves the use of chemicals of high concern as defined by GreenScreen® Benchmark 1.
- Manufacturing step involves the use of chemicals determined to be "unspecified" due to the lack of complete hazard data using GreenScreen®.

Notes:
- Only the principal input chemicals are included in this analysis (see Appendix 3).
- For each step, the score is based on the worst performing chemical for human and environmental health. Thus, if any step includes a chemical of high concern, then it receives a zero.
- All steps are considered of equal weight and are scaled to 100—with the green polymer scoring "100" and the red polymer scoring "0".

		Included	Not-included
Scope of the assessment	Plastic use & waste generation		X
	Circularity		X
	Plastic leakage		X
	Environmental impacts (from plastic leakage)	X	X
	Microplastics		X
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific		X
	Sector specific		X
	Country specific		X
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available		X
	Case studies available (related to plastic leakage)	X	

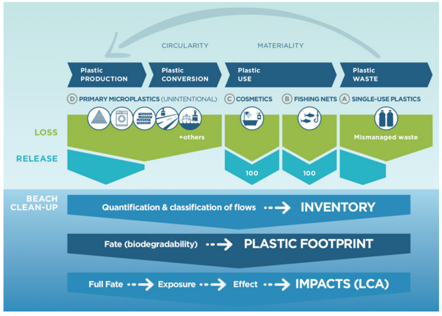
Marine Plastic Footprint

The Marine Plastic Footprint

IUCN / EA

Method available since June 2019

n.a.



The Marine Plastic Footprint methodology was being developed by IUCN in collaboration with EA. It builds upon the inventory of different plastic losses over the life cycle of businesses or products. It cross-links the concepts of plastic leakage (inventory), plastic circularity (fraction of plastic recycled or restored in biological cycles) and plastic materiality (ratio of the functionality/added value versus potential impacts). Loss rates and plastic fate[1] are based on gross assumptions. The proposed methodology encompasses both mismanaged plastic waste and microplastics from different sources. It provides default emission factors for key sectors.

Two case studies are under development, in the Mediterranean and Baltic regions.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage	X	
	Fate of Plastic Leakage	X	
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)		X
	Application specific	X	
	Sector specific	X	
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available		X
	Dataset available	X	
	Case studies available (related to plastic leakage)	X	

1 See Chapter 4 and glossary section 7.3.9

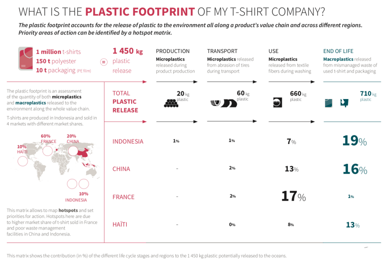
Plastic Leak Project

The Plastic Leak Project

QUANTIS / EA

Not available yet – available end of 2019

https://quantis-intl.com/metrics/initiatives/plastic-leak-project/



The Plastic Leak Project, launched by Quantis and EA, is a pre-competitive project involving industries from different sectors. The objective is to refine the inventory method for plastic flows released into the environment and develop generic datasets, enabling use of the methodology by companies.

The approach is targeting both the macro-component from mismanaged wastes and microplastics from different sources. It is intended to complement the LCA framework with better inventory data for plastics and prepare a dedicated impact assessment method for marine plastics.

The project gathers 25 companies and includes a strategic committee (IUCN, UN Environment and the World Business Council for Sustainable Development), as well as an advisory board composed of 15 universities or NGO members. It is structured around three working groups focusing on packaging, textiles and tyres.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity		X
	Plastic leakage	X	
	Fate of Plastic Leakage	X	
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific	X	
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available	X	
	Case studies available (related to plastic leakage)	X	

Circularity Indicators

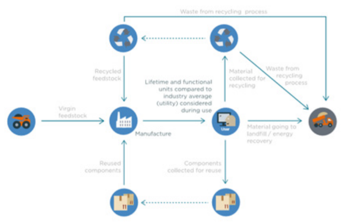
Circularity Indicators Project

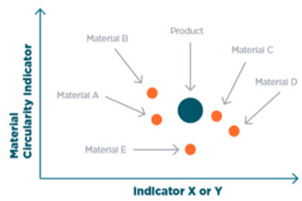
Ellen MacArthur Foundation

2016

https://quantis-intl.com/metrics/initiatives/plastic-leak-project/
https://www.ellenmacarthurfoundation.org/resources/apply/circularity-indicators

The Circularity Indicators Project, developed by the Ellen MacArthur Foundation, provides companies with a methodology and tool to assess their progress towards a circular economy model. It allows companies to estimate how advanced they are on their journey from linear to circular supply chains by measuring how restorative the material flows of a product or company are – the Material Circularity Indicator. Additional complementary indicators take other impacts and risks into account. Together with the methodology, the project has contributed to the development of a commercially-available web-based tool allowing businesses to track their progress. These tools are intended for use in product design but could also be used for internal reporting or procurement and investment decisions. Furthermore, variants or extensions of the indicators could be used in education, research, rating or policymaking.





		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	X
	Plastic leakage		X
	Fate of Plastic Leakage		X
	Environmental impacts (from plastic leakage)		X
	Microplastics		X
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific		X
	Country specific		X
	Archetype specific (by income level)		X
Description of the tool	Online version	X	
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available		X
	Dataset available		X
	Case studies available (related to plastic leakage)		X

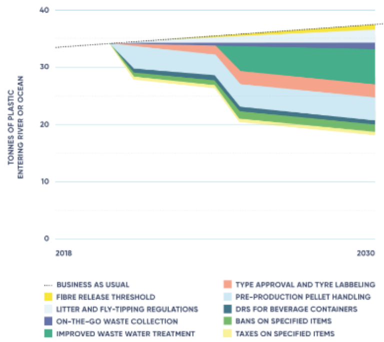
Plastic Drawdown

Plastic Drawdown	
	Plastic Drawdown
	Common Seas
	Developed and available for use
	https://commonseas.com/projects/plastic-drawdown

Plastic Drawdown allows governments to understand plastic waste flows within their country and identify a portfolio of policies that addresses their country's plastic waste and pollution challenge. The objective is to establish evidence-based strategies that lead to action across the plastics value chain to prevent plastic leaking into rivers and ocean. Plastic Drawdown includes a model of waste flows, policy guidance, and a wedges tool that collectively:

- Describes a county's plastic waste mass and composition, including the microplastics and macroplastics that most commonly leak, and how this would change under a business-as-usual projection to 2030.
- Models plastic waste flows to identify leakage characteristics and quantify the mass of plastics entering the watercourse.
- Reviews and models the impact of 18 policies, providing guidance to support planning, specification and implementation.
- Visualises leakage data within an interactive wedges tool that can be used to investigate the impact of different policy strategies.

Plastic Drawdown enables governments at a national or regional level to convene key actors, target and build consensus around the key plastic flows, and develop an action plan of locally appropriate and effective interventions.



It has been delivered in partnership with Eunomia, with support from an advisory group representing universities, NGOs and government.

At publication, Plastic Drawdown has been delivered in Indonesia, Greece, the United Kingdom, and is being developed in the Maldives. It is ready to be applied worldwide and is proposed as part of a globally consistent approach for addressing marine plastic pollution.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage	X	
	Environmental impacts		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)		X
	Application specific	X	
	Sector specific	X	
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis	X	
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available	X	
	Case studies available (related to plastic leakage)	X	

Marine Impacts in LCA	
	Marine Impacts in LCA
	CIRAIG / PUCP / NTNU
	Not available yet
	n.a.

Impacts from marine litter, including plastic, are currently not included in life cycle impact assessment. This international working group, bringing together the International Reference Centre for the Life Cycle Products, Processes and Services (CIRAIG), the Pontificia Universidad Católica del Perú (PUCP) and the Norwegian University of Science and Technology (NTNU), will foster and coordinate research on marine impacts in LCA. This work is supported by the UN Environment Life Cycle Initiative and the Forum for Sustainability through Life Cycle Innovation (FSLCI). It started in late 2018 and will be finalised by 2025. In the short term, it will deliver a framework for integrating impact assessment of marine plastics in LCA, and in the longer term, it will develop specific characterisation models to quantify impact pathways for plastics.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation		X
	Circularity		X
	Plastic leakage		X
	Environmental impacts (from plastic leakage)	X	
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific		X
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available		X
	Dataset available	X	
	Case studies available (related to plastic leakage)		X

PlastikBudget

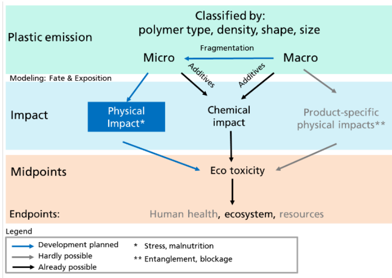
Development of Budget Approach and LCA Impact Assessment Methodology for the Governance of Plastic in the Environment

Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT and the Institute for Advanced Study in the Humanities (KWI)

Not available yet

n.a.

The PlastikBudget[2] project, developed by Fraunnhofer UMSICHT and KWI, aims to create a basis for future political decision-making by providing empirically verified data and normative values from which a per capita plastic emission budget can be derived. Scientific findings on the sources, quantities and effects of plastics in the environment are measured and the interests of relevant actors are brought together. Corresponding midpoint and endpoint indicators and associated characterisation methodologies, as well as standardisation to a reference value (e.g. by the production volume of the specific plastic) are also included.



		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity		X
	Plastic leakage	X	
	Fate of Plastic Leakage	X	
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific		X
	Country specific		X
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	n.a.	n.a.
	Data collection guidance available	n.a.	n.a.
	Dataset available	n.a.	n.a.
	Case studies available (related to plastic leakage)	n.a.	n.a.

2 Sometimes referred to with the English Spelling as PlasticBudget.

Plastic Pollution Calculator

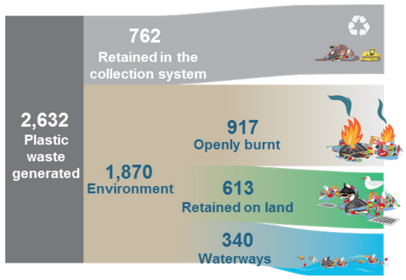
ISWA PLASTIC WASTE POLLUTION CALCULATOR

The International Solid Waste Association (ISWA)

Developed – Under testing

http://marinelitter.iswa.org/

The ISWA Plastic Waste Pollution Calculator is a toolkit developed by the University of Leeds on behalf of the Task Force on Marine Litter, an initiative of ISWA. Its objective is to allow municipalities, NGOs and governments to map the flow over time of macro-sized plastic waste items throughout their region, from the point of generation to their eventual disposal or fate in the environment.



By answering a series of questions on the local socio-economic, environmental and technical conditions, particularly regarding the details of waste and resources management techniques and infrastructure, the calculator is able to identify mechanisms by which plastic items may become mismanaged and subsequently transported to waterways based on each item's physical properties. As the flow of mass is mapped throughout the waste management system, this allows the quantification of plastic pollution sources and identification of prioritised interventions.

The tool is applied at a district (neighbourhood) level, however results can be combined to analyse waste flows over larger regions or on a watershed level. Two levels of assessment, broad and detailed, allow greater flexibility based on local requirements and resources.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity		X
	Plastic leakage	X	
	Environmental impacts (from plastic leakage)	X	
	Microplastics		X
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific		X
	Sector specific	X	
	Country specific	X	
	Archetype specific (by income level)	X	
Description of the tool	Online version	X (planned for 2020)	
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis	X	
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available	X	
	Case studies available (related to plastic leakage)	X	

PET GA PET Collection

PET GA PET Collection, Landfill and Environmental Leakage Rates in SEA (Southeast Asia)

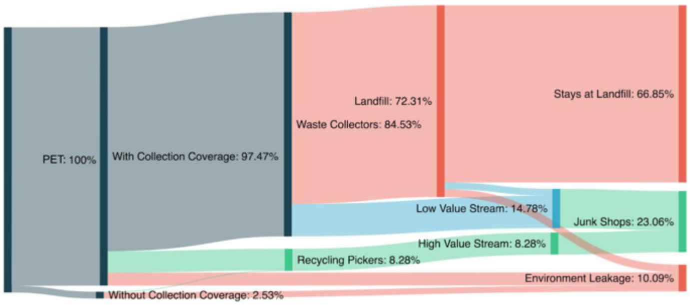
GA Circular and businesses

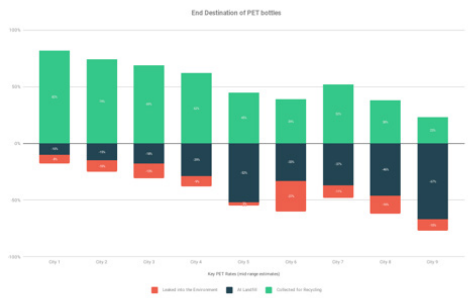
Not available yet – available end of 2019

https://www.gacircular.com/publications/

The study's objective is to quantify, for the first time, the baseline rates for PET collection, recycling, landfill and environmental leakage in the key cities of six countries in Southeast Asia (Indonesia, Philippines, Vietnam, Thailand, Malaysia and Myanmar) and to extrapolate a national rate. To this end, the study collects data through the informal and formal value chains and the recycling industry, as well as analysing current waste management systems and quantifying past interventions/initiatives. The study additionally forecasts intervention scenarios by companies, industry, government and a combination thereof.

The findings of the studies are to be presented to industry, government, academia and international funding organisations in each country to build a common understanding among all stakeholders regarding the current baseline and intervention scenarios – enabling informed decision making and a baseline with which to track progress. The results of the six countries are being synthesised into an ASEAN report for publication.





		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage	X	
	Environmental impacts (from plastic leakage)		X
	Microplastics		X
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific	X	
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version	X	
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis	X	
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available		X
	Dataset available		X
	Case studies available (related to plastic leakage)	X	

Plastic Life Cycle

Plastic Life Cycle Assessment

European Commission, Joint Research Centre, Ispra, Italy

Draft method available since November 2018

https://eplca.jrc.ec.europa.eu/permalink/PLASTIC_LCI/Plastic_LCA_Report_I_2018.11.20.pdf

In the context of the Plastics Strategy (COM(2018) 28 final), the JRC was entrusted by the Directorate-General for Internal market, Industry, Entrepreneurship and SMEs (DG GROW) with the project *"Environmental sustainability assessment comparing through the means of lifecycle assessment the potential environmental impacts of the use of alternative feedstocks (biomass, recycled plastics, CO2) for plastic articles in comparison to using current feedstocks (oil and gas)"*. The objective is to elaborate a consistent LCA method, including the end of life treatment, for different plastics. The approach is to take into account learnings from the Environmental Footprint (Recommendation 2013/179/EU) pilot phase and insights on indirect land use change from the biofuels discussions.


JRC TECHNICAL REPORTS

Environmental sustainability assessment comparing through the means of lifecycle assessment the potential environmental impacts of the use of alternative feedstock (biomass, recycled plastics, CO2) for plastic articles in comparison to using current feedstock (oil and gas)

Draft report for stakeholder consultation (part 1):
- *Meta-analysis of selected existing studies*
- *Draft method for LCA of plastics*

Authors: Nessi S., Bulgheroni C., Konti A., Sinkko T., Tonini D., Pant R. (project leader)

Deadline for consultation comments: December 19, 2018

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage	X	
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific		X
	Country specific		X
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available		X
	Case studies available (related to plastic leakage)		X

PiPro SEA	
	Pioneer Project SEA
	Ellen MacArthur Foundation companies
	Not available yet – available end of 2019
	n.a.

The SEA Approach is a multi-stakeholder project involving partners from different sectors including multinationals, governments, NGOs and businesses. It aims to build in-depth common understanding and share existing knowledge of formal and informal waste management systems in priority countries Indonesia, Philippines and India. The approach will generate data on how waste management systems are organised and function, identifying the proportions of recovered and non-recovered plastics. This will make it possible to highlight which plastics and packaging formats need to be addressed in order to prevent them from ending up in landfill and dumpsites or as litter. The project started in May 2017, and the final results are expected in late 2018. The project's deliverables include an assessment framework for replicating data generation in all markets. The framework also includes a glossary and reliable data on waste flows (incl. packaging waste). The project does not include any impact assessment of plastic leakage.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage		X
	Fate of Plastic Leakage		X
	Environmental impacts (from plastic leakage)		X
	Microplastics		X
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific	X	
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available		X
	Case studies available (related to plastic leakage)	X	

Marine Plastic Hotspotting

National Guidance For Marine Plastic Hotspotting and Shaping Action

UN Environment / IUCN

Not available yet – available end of 2019

n.a.

This methodological guidance is being developed by UN Environment and IUCN to identify key plastic hotspots with respect to the most relevant products, streams and influxes, and stakeholders related to plastic waste emitted into the marine environment at a national level. The analysis is intended to relate to the magnitude of flows and impact, and associated stakeholders along the value chain of plastic, as well as to identify potential instruments (policy, technology, awareness) to address hotspots, with a strong regional dimension. Such guidance is expected to be validated in one case study country.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage	X	
	Fate of Plastic Leakage	X	
	Environmental impacts (from plastic leakage)	X	
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific	X	
	Sector specific	X	
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available	X	
	Dataset available	X	
	Case studies available (related to plastic leakage)	X	

SYSTEMIQ Roadmap

A Global Roadmap to Achieve Near-zero Ocean Plastic Leakage

SYSTEMIQ / PEW

Not available yet – available end of 2019

n.a.

The Global Roadmap to Achieve Near-zero Ocean Plastic Leakage provides robust, evidence-driven analysis to policymakers, industry leaders and other key stakeholders to highlight the costs and trade-offs associated with technological and policy changes required to pursue near-zero leakage strategies for different geographic 'archetypes[3]'. The roadmap is solution oriented but implies the development of a leakage estimation model based on different leakage pathways for both macro- and micro- plastics.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity	X	
	Plastic leakage	X	
	Fate of Plastic Leakage		X
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)	X	
	Application specific		
	Sector specific		X
	Country specific		X
	Archetype specific (by income level)	X	
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available	X	
	Data collection guidance available		X
	Dataset available	X	
	Case studies available (related to plastic leakage)		X

3 Geographic archetypes are defined as a set of countries with similar socio-economic and/or geographic features

Plastic Footprinter

Plastic Footprinter

Race for Water Foundation

2014

http://plasticfootprint.ch

The R4W tool was developed by the Race for Water Foundation in partnership with EA. It aims to raise awareness and drive action by measuring an individual person's plastic footprint and its related impact. The tool uses an online survey of 15 questions to determine the weight of plastics used per year and the weight of the portion that would leak into the ocean. It mainly accounts for single use plastics, microbeads in cosmetics and cigarette butts. On completing the survey, users are proposed actions to reduce their plastic footprint.

		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity		X
	Plastic leakage	X	
	Fate of Plastic Leakage		X
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)		X
	Application specific		X
	Sector specific		X
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version		X
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available		X
	Data collection guidance available		X
	Dataset available		X
	Case studies available (related to plastic leakage)		X

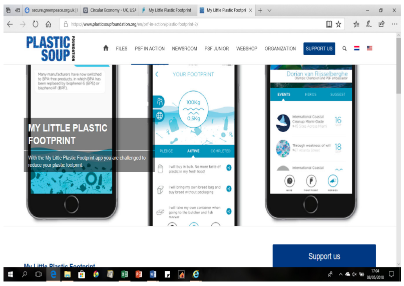
My Little Plastic Footprint

Plastic Soup Foundation

2017

https://mylittleplasticfootprint.org

My Little Plastic Footprint is a smartphone app for individuals, developed by UN Environment through their Clean Seas campaign in partnership with the Plastic Soup Foundation, Smäll, Ocean Recovery Alliance and EA. By using gamification[4], through a quiz with over 100 questions, the aim is to encourage those who use the app to reduce their plastic footprint and become more conscious of their own actions.



		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity		X
	Plastic leakage	X	
	Fate of Plastic Leakage		X
	Environmental impacts (from plastic leakage)		X
	Microplastics	X	
Granularity of the assessment	Polymer specific (but not related to littering)		X
	Application specific		X
	Sector specific		X
	Country specific	X	
	Archetype specific (by income level)		X
Description of the tool	Online version	X	
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available		X
	Data collection guidance available		X
	Dataset available		X
	Case studies available (related to plastic leakage)		X

4 Gaification is the integration of game elements in non-game contexts

Plastics Calculator

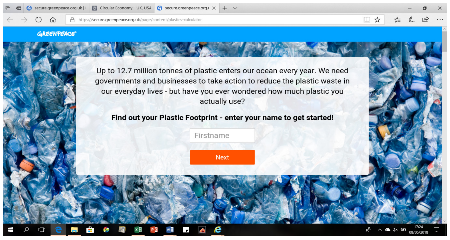
Plastics Calculator

Greenpeace

2016

https://quantis-intl.com/metrics/initiatives/plastic-leak-project/
https://secure.greenpeace.org.uk/page/content/plastics-calculator

The Plastics Calculator is a tool developed by Greenpeace to raise awareness of a person's individual impact within the larger context of plastic pollution. Targeting people based in the UK, it asks questions about lifestyle and purchasing decisions to create an estimate of personal plastic use and waste.



		Included	Not-included
Scope of the assessment	Plastic use & waste generation	X	
	Circularity		X
	Plastic leakage		X
	Fate of Plastic Leakage		X
	Environmental impacts (from plastic leakage)		X
	Microplastics		X
Granularity of the assessment	Polymer specific (but not related to littering)		X
	Application specific		X
	Sector specific		X
	Country specific		X
	Archetype specific (by income level)		X
Description of the tool	Online version	X	
	Labelling/accreditation scheme		X
	Includes forecasting and scenario analysis		X
Description of the guidance	Calculation rules transparent and available		X
	Data collection guidance available		X
	Dataset available		X
	Case studies available (related to plastic leakage)		X

3.3. Typology of the plastic footprint methodologies reviewed

Depending on the purpose of each (see Chapter 2), the existing methodologies and those under development can be classified in different manners. For example, classification can be applied on the:

- **Modelling rules**: flexible to enable a high level of specificity *versus* based on a standardised framework to ensure comparability.
- **Output metrics**: an inventory of pollutants flows *versus* impact indicators.
- **Actionability**: a single indicator for action *versus* multiple criteria in order to anticipate the trade-off between different environmental issues.

3.3.1. First level of analysis: Actionability *versus* Accountability

The typology framework is based on two axes as captured in Figure 9.

The X-axis characterizes what the methodology is accountable for, i.e. the output metric, and is divided into three categories:

1. **Use or waste of plastics**: the output metric is a measure of a quantity of plastics used or wasted (mass unit) or a measurement of the circularity of the system (index or recycling rate);
2. **Loss and release:** the output metric is a measure of the plastics leaking from the technosphere[1] into the environment (mass unit), i.e. the plastic footprint consists of an

[1] That part of the environment that is made or modified by humans.

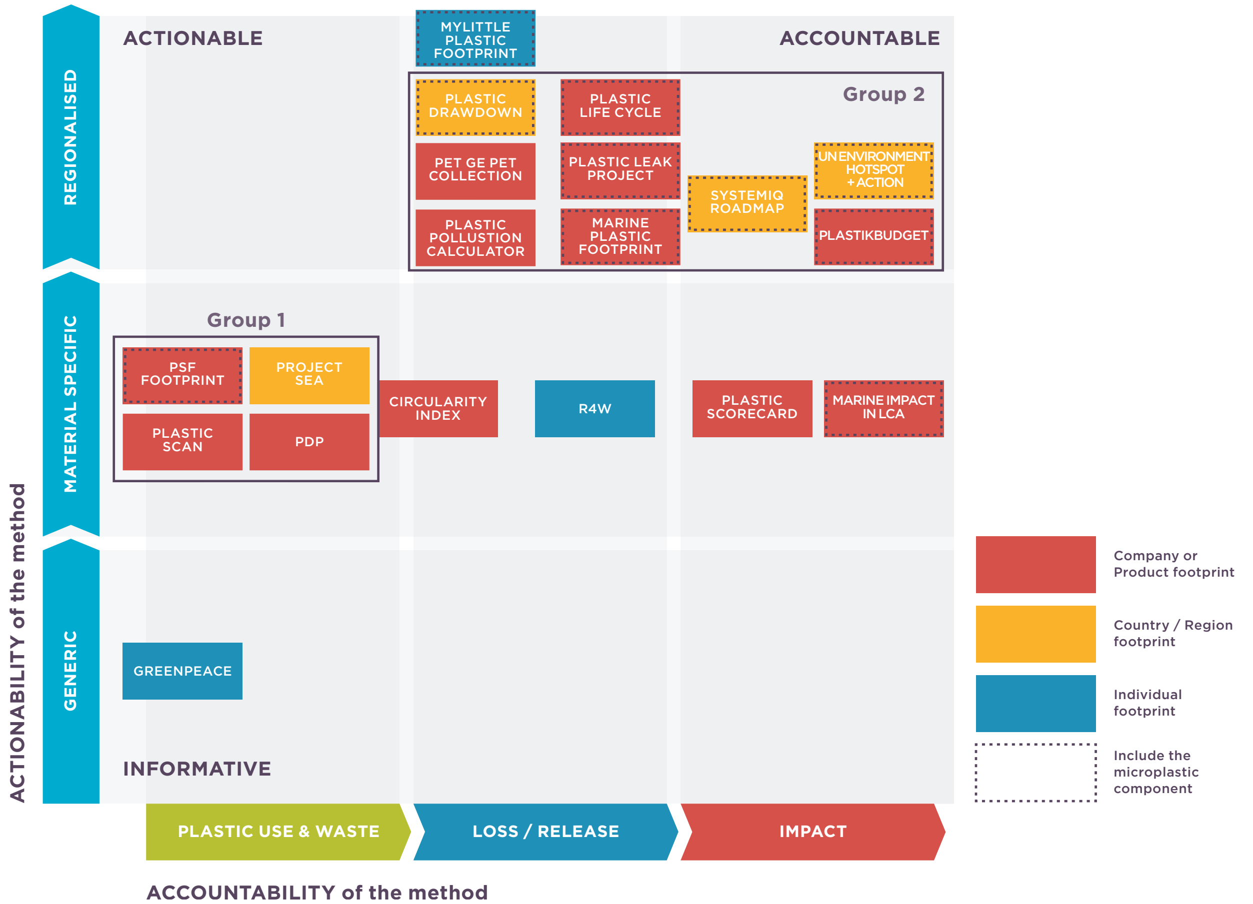


Figure 9. Typology framework of plastic footprint methodologies | Actionability versus Accountability.

Key learnings

- Two groupings emerge from the typology framework, both including product- or company-level and national- or regional-level plastic footprint methodologies:
    - Group 1 includes the PSF Plastic Footprint, SEA Approach, Plastic Scan, and the Plastic Disclosure Project (PDP), all of which provide the user with information on different plastic waste streams and recycling rates. In addition, the PSF Plastic Footprint and PDP provide a list of actions towards reducing the plastic footprint of the entity using the methodology. None of these methodologies include a plastic leakage assessment.
    - Group 2 includes the Marine Plastic Footprint, the National Guidance For Marine Plastic Hotspotting and Shaping Action, the SYSTEMIQ Global Roadmap, the Plastic Leak Project, JRC LCA guidelines, Plastic Drawdown, ISWA PPC, PET GA and PlastikBudget, all of which focus on the leakage pathway and allow the establishment of a plastic leakage inventory for different plastic types and life cycle stages.
- A good level of complementarity is evident within the two groups. Group 1 contains data-focused projects that will improve the quality of the supporting data required to calculate footprints (e.g. SEA Approach). The Group 2 projects focus more on developing calculation rules and modelling leakage pathways, enabling the creation of synthetic metrics to support decision-making and monitor progress. Some methodologies, such as the SYSTEMIQ Global Roadmap or the UN Environment - IUCN guidance, include a 'solution' component to inform and guide decision-making towards reducing plastic leakages.
- The Circularity Indicators Project is the only existing methodology to measure the circularity of a business supply chain.
- There is currently no methodology allowing to measure the trade-off between different impact categories. The methodology being developed by UN Environment intends to provide the user with a qualitative assessment of the environmental impacts of the plastic leakage resulting from different plastic applications, in order to define priorities for actions (hotspots). The Plastic Leak Project, JRC LCA guidelines and the MariLCA project are aiming to develop guidance on how to integrate plastic leakage in the framework of LCA by developing inventory and impact assessment pathways.
- Despite the very high and increasing public awareness of plastic pollution and its related environmental, economic and social impacts, the number of methodologies available to calculate the plastic footprint of individuals is relatively limited.

inventory methodology in the sense of LCA (see section 2.2.1); and

3. **Impacts**: the output metric is a measure of the environmental impacts generated by the plastic leakage (e.g. unit of biodiversity loss or harm to human health).

The Y-axis characterises the focus of the actionable component of the methodology (when included). It is based on three categories:

1. **Generic**: plastic types are not distinguished.
2. **Material specific**: plastic types are distinguished by polymer (e.g. polyvinyl chloride (PVC), polyethylene (PE), etc.) and format (e.g. rigid *versus* flexible).
3. **Regionalised**: plastic leakage is assessed in different geographies through regionalised factors such as mismanaged waste ratio, distance to shore or waste water treatment efficiencies. Methodologies with a regionalised actionable component account for regional specificities in the release rate of plastics that relate strongly to local infrastructure.

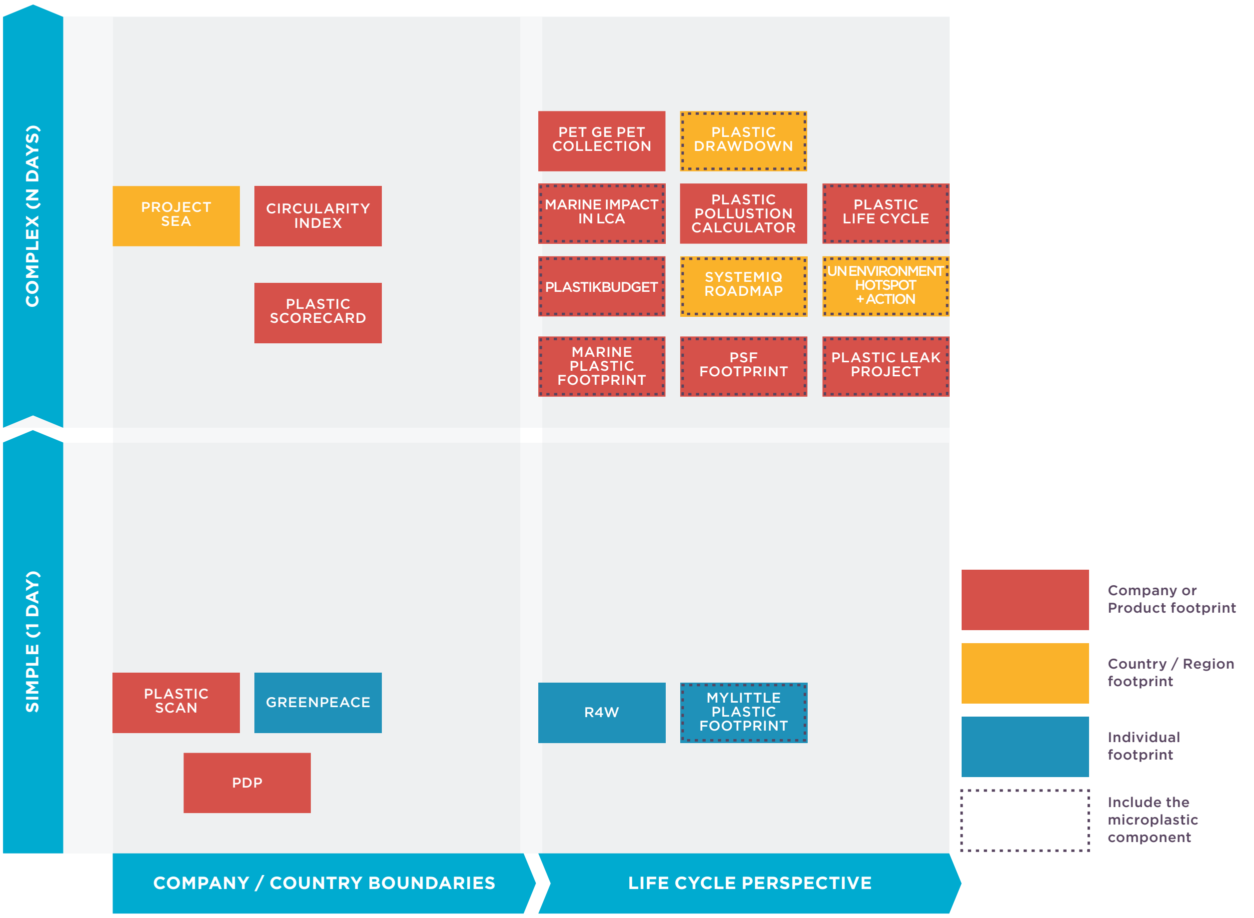


Figure 10. Typology framework of plastic footprint methodologies | Simplicity versus Life Cycle Perspective.

3.3.2. Second level of analysis: Simplicity *versus* Life Cycle Perspective

For the second level of analysis, the typology framework captured in Figure 10 is again based on two axes.

The X-axis characterises the scope of the reviewed methodologies on either an entity (i.e. a business, a country or a region) or a life cycle (plastic use and waste in all stages of the plastic life cycle).

The Y-axis characterises simplicity or complexity of the methodologies based on the number of days it takes to use and apply them.

Key learnings

- Individual footprints are simple methodologies, quick to complete.
- Methodologies targeting companies or geographical entities are more complex as they require a greater time investment mainly for data collection.
- The development of new methodologies has significantly increased in 2018 and 2019.
- There is still no robust impact assessment method in place, to allow full alignment of plastic leakage approaches with the LCA framework (MariLCA intends to close this gap in the future).
- Plastic leakage assessment is improving fast due to better understanding of the leakage pathways and availability of data.

What the review demonstrates

This review of methodologies demonstrates that this is a fast moving and recently emerged area of development that attracts many different players. It is apparent that there could be stronger convergence between the methodologies. This report aims to identify complementarity and synergies between the various methodologies reviewed while also pointing towards features that should be included in newly developed methodologies.

Existing plastic footprints methodologies lack:

- data on plastic waste management at country level;
- pathway models accounting for both microplastic and macroplastic leakage;
- fate models (see section 4.1.1) including both degradation and fragmentation of plastics once exposed to the marine environment as well as transfer into different environmental compartments; and
- impact assessment methodologies accounting for the negative effects of plastics on human health and ecosystems based the latest available toxicological and ecotoxicological data.

4. Existing plastic impact assessment methodologies

As stated in Chapter 2, the LCA methodologies are starting to integrate plastics as a pollutant, mainly in inventories, i.e. assessments of the amount of plastic lost throughout a product life cycle. In addition, the assessment of plastic waste impacts on biodiversity or humans through LCA is currently in development (Sonnemann & Valdivia, 2017; Woods et al., 2016). This gap is not exclusive to LCA. Although initiatives are being launched to fill this gap, there is to date no plastic footprint methodology including impact assessment.

This chapter presents the current state of knowledge on impact assessment for plastics.

4.1. Plastic impact assessment for ecosystems and biodiversity

To date, no methodology exists to perform a quantitative plastic impact assessment. This gap is not exclusive to LCA: there is currently no operational methodology which allows for the quantification of these impacts. However, scientists have made attempts to qualify plastic impacts. Figure 11 summarises the different modelling stages included in these existing methodologies, which allow the impacts of plastic on biodiversity/ecosystems to be described.

The different modelling stages are described in greater detail in the following sections.

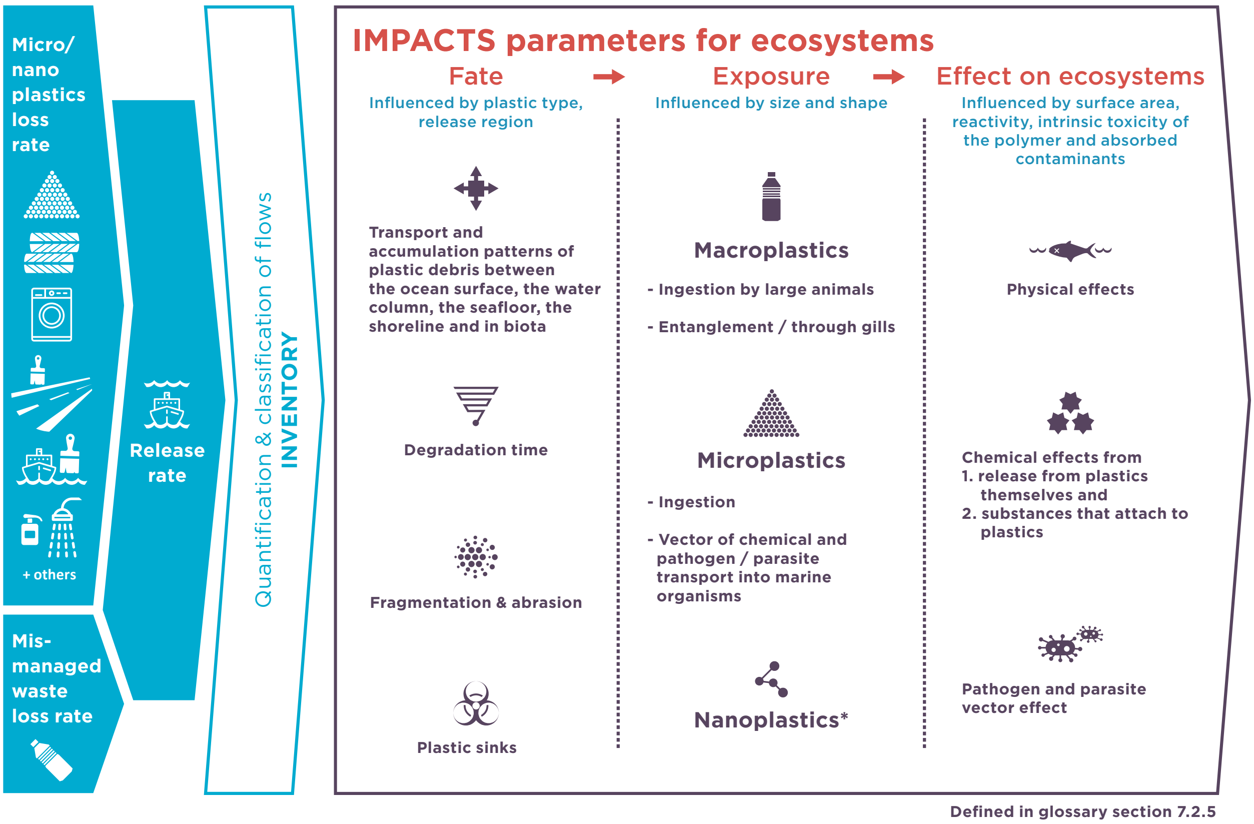


Figure 11. Plastic impact assessment for ecosystems and biodiversity.

Figure 12. Fate process.

4.1.1. Fate factor

In a nutshell
For microplastics and macroplastics, the fate starts with transport to surface waterways, transfer to the ocean, and finally to the ocean compartment where they then accumulate (ocean surface, water column, sediments, biota, etc.). In this journey, plastics of different sizes and shapes may be fragmented and potentially degraded at different rates, but this process is currently not well understood, neither in the freshwater nor in the seawater compartments.

The first modelling stage of existing plastic impact assessment methodologies relates to the fate of plastics once released in the environment. The fate factor links the quantity of plastics ending up in the environment with the chemical masses (or concentrations) in a given compartment (Rosenbaum et al., 2011) through multimedia mass balance modelling[2] (Mackay, 2002). It accounts for multimedia and spatial transport between the environmental media (e.g. air, water, soil, etc.). The fate factor models the spatial distribution and intensity of a unit intervention and is generally obtained from environmental fate models (Curran et al., 2011). The fate represents the persistence of a plastic in the environment (e.g. in days) and depends on the polymer type and size as well as the environmental conditions of the emission and release media, such as, for example, the exposure to sun or temperature. The longer the residence time, the longer a plastic remains in the environment and can be harmful for ecosystems or humans.

Woods et al. (2016) distinguish two categories of existing quantitative approaches which:

1. estimate the transport of land-based plastic waste to the marine environment (Jambeck, 2015); and

2. model the transport and accumulation patterns of plastic in the marine environment (Lebreton et al., 2017).

Based on this, a fate factor could express the fraction of land-based plastic waste that is transported to the marine environment and the accumulation zones to which it is transported according to the country of origin of the plastic waste (Woods et al., 2016).

A key difference between the fate of chemical substances and the fate of plastics is the influence of the plastic type and the plastic size on the transport and degradation process. Given that a distinction is made between microplastics and macroplastics, fragmentation (formation of surface cracks and pits), degradation into microplastics and nanoplastics[3], and ultimately mineralization (destruction of the polymer chain and its complete conversion into small molecules such as carbon dioxide or methane) as a function of residence time need to be taken into account.

[2] Multimedia mass balance models are models that cover the transport of chemicals from the medium of emission into another medium (e.g. air, soil, freshwater and ocean) and results in various exposure pathway for ecosystems and humans. Compartment and place of emission, pollutant decay rate in different media, partitioning coefficients and bioaccumulation factors are important parameters considered in these models

[3] See glossary section 7.2.5

In a nutshell
The exposure, i.e. the way plastics enter into contact with an organism, greatly depends on the size (macro, micro or nano) and type (see glossary for plastic types) of the particle. Plastics can enter into contact through an organism's gills, ingestion, tissues, cells and organelles, be excreted, or act as vector for chemicals or biological pathogens and parasites.

4.1.2. Exposure factor

The second modelling stage of existing plastic impact assessment methodologies relates to biodiversity/ecosystem exposure to plastic. The exposure factor links the quantity of chemicals in a given environmental compartment with chemical intake by humans or chemical exposure of ecosystems. For the toxic impact of plastics on aquatic ecosystems, it can be equal to the fraction of substance present in dissolved form (Rosenbaum et al., 2008), the underlying hypothesis being that the ecosystem is exposed to the dissolved part of the chemicals reaching freshwater systems. For the toxic impact of plastics on humans, the exposure factor can distinguish between direct intake (e.g. by breathing air and drinking water), indirect intake through bioconcentration[4] processes in animal tissues (e.g. meat, milk, and fish) and intake through dermal contact.

GESAMP is the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, a body that advises United Nations organisations on the scientific aspects of marine environmental protection. The GESAMP (2016) report specifies that in the case of marine plastics, the exposure of marine organisms can occur through the following pathways:

- gills
- ingestion
- tissues, cells and organelles
- excretion
- microplastics as a vector of chemical, pathogens and parasites transport into marine organisms (e.g. POPs[5], PBTs[6], metals).

Humans are exposed to plastics through the ingestion of these marine organisms (GESAMP, 2015).

4.1.3. Effect factor

The third modelling stage of existing plastic impact assessment methodologies relates to biodiversity/ecosystem exposure to plastic. The effect factor links the level of exposure of a given population or ecosystem with the caused impact. It relates the intensity of the exposure to a quantified effect, such as the potentially disappeared fraction (PDF) of species (Curran et al., 2011). For example, the aquatic ecotoxicity effect factor refers to the response of aquatic species to a chemical concentration increase in freshwater systems.

Woods et al. (2016) state that there are currently no effect factor models included in an impact assessment which would enable quantification of the effect of plastic on biodiversity. Further research is required to understand the sensitivity of species to the effects of plastics at the population, community and ecosystem scales, i.e. elucidating the significance of reported individual mortalities at larger scales.

However, even if to date there is no quantitative effect factor, there is qualitative assessment measuring the different types of impacts caused

[4] Bioconcentration is the process by which a chemical concentration in an aquatic organism exceeds that in water as a result of exposure to a waterborne chemical.

[5] Persistent organic pollutants (POPs) are organic compounds that are resistant to environmental degradation through chemical, biological and photolytic processes.

[6] Persistent, bioaccumulative and toxic substances (PBTs) are a class of compounds that have high resistance to degradation from abiotic and biotic factors, high mobility in the environment and high toxicity.

by plastics on species (Romée de Blois, 2016). The type of impact depends on the characteristics of the plastics and their size. Roughly three different types of impacts can be distinguished: physical, chemical, and pathogen and parasite vector impacts. It is often difficult to assign a particular impact to the polymer, the additives or the substances / pathogens that the plastic serve as a vector for. Due to the risk of mechanical hazard, macroplastic and microplastic polymers can be associated with physical impacts. Conclusive evidence of adverse effects caused by chemicals associated with microplastics remains difficult to obtain (GESAMP, 2015).

Physical impacts are mainly caused by the polymers, the primary building blocks of plastics. Well-known examples of these impacts are entanglement and ingestion by sea animals (e.g. obstruction of feeding organs). Plastics have been ingested by and/or entangled many different organisms around the world, including turtles, fish, seabirds and crustaceans (Cole et al., 2011; Derraik, 2002; Moore et al., 2009; Ryan et al., 2009). When plastics are or become smaller, they are more easily ingested by aquatic life. Even algae are found to have absorbed nanoplastics, which resulted in a decreased ability to photosynthesise and recover from oxidative stress (Bhattacharya et al., 2010). Zooplankton is also found to be affected by microplastics adhering to its appendages, decreasing their functionality and reducing the feeding ability of algae (Cole et al., 2013).

Ingestion by organisms at low trophic levels is especially dangerous because they are the basis of their entire ecosystem and might pass on the ingested plastics to higher trophic levels. This phenomenon is known as biomagnification or accumulation through the food chain (Browne et al., 2013). Ingested plastics can cause reduced food consumption, blockage of the intestinal tract, reduced feeding stimuli, inhibition of gastric enzyme secretion, decreased steroid hormone levels, ovulation delays, failure to reproduce, impaired energy and metabolism management, and overall reduced fitness (Azzarello & Van Vleet, 1987; Derraik, 2002; McCauley & Bjorndal, 1999; Spear et al., 1995; Wright et al., 2013).

Chemical impacts caused by plastics are often characterised as toxic to humans and ecosystems. Macroplastics, microplastics and nanoplastics can release chemical additives, residual monomers (i.e. degradation products of plastic polymers) and other chemicals (Galloway, 2015; GESAMP, 2015). Environmental forces like ultraviolet light and heat degradation from the sun, hydraulic degradation from ocean currents, waves and tides, and biodegradation all cause plastics to become unstable and fragment (Pastorelli et al., 2014).

Chemical additives like phthalates and brominated flame retardants, are recognised to cause endocrine disruption when inhaled and ingested (Galloway, 2015; GESAMP, 2015). Low concentrations of these additives have also been shown to harm several species (e.g. seabirds and lugworms) through the reduction of some biological function or a population decrease (GESAMP, 2015; Verboven et al., 2008; Verreault et al., 2006).

Pathogen and parasite vector impacts. Plastics, when accidentally ingested by bigger organisms, can serve as a substrate for parasites and micro-organisms attached to them (GESAMP, 2015; McCormick et al., 2014; van der Meulen et al., 2015). In addition to the physical impacts that this ingested plastic can cause on the bigger organism, the parasites and micro-organisms might also cause additional health impacts. This is another pathway through which microplastics can serve as a “Trojan Horse”. For instance, a study on the colonization of stranded plastic debris in Arctic and Antarctic islands estimated that human litter more than doubles the rafting opportunities for biota (Barnes, 2002; GESAMP, 2015), increasing the risk of dispersal of aggressive alien and invasive species and thus endangering sensitive coastal habitats.

Although no comprehensive framework linking plastic characteristics (polymer type, additives, size, shape, etc.) to their effect exists yet, Woods et al. (2016) recommend the development of several effect factors according to differing types of plastic and related effects (physical, chemical

In a nutshell

There are three main types of impacts caused by plastics:

1. Physical impacts, which relate to the size and shape of the polymer entering into contact with an organism, leading, for example, to entanglement or ingestion.
2. Chemical impacts, which relate to the toxicity of substances released by plastics.
3. Pathogen and parasite vector impacts, when plastic debris serve as a substrate for parasites and micro-organisms.

or pathogen and parasite vector impact). For example:

- The majority of entanglement encounters occur with macroplastics, such as rope and netting.
- The majority of ingestion incidents occur with microplastics (Gall & Thompson, 2015).
- Time horizon considerations need to be improved through better understanding of the degradation rate of plastic, associated plastic fragment size class distribution and plastic sinks identification, i.e. mechanisms through which the exposure of marine biodiversity to plastic debris are arrested.

4.2. Plastic impact assessment for human health

Plastics can affect human health through several routes, including drinking water, bathing water, inhalation from air and/or via active contact with cosmetics or foods such as honey, beer, salt, etc. This report focuses on impacts related to marine plastic debris to which marine organisms are exposed, and which in turn affect humans through dietary exposure. This remains an under-investigated field in which robust scientific evidence of the impacts of plastics on human health is lacking.

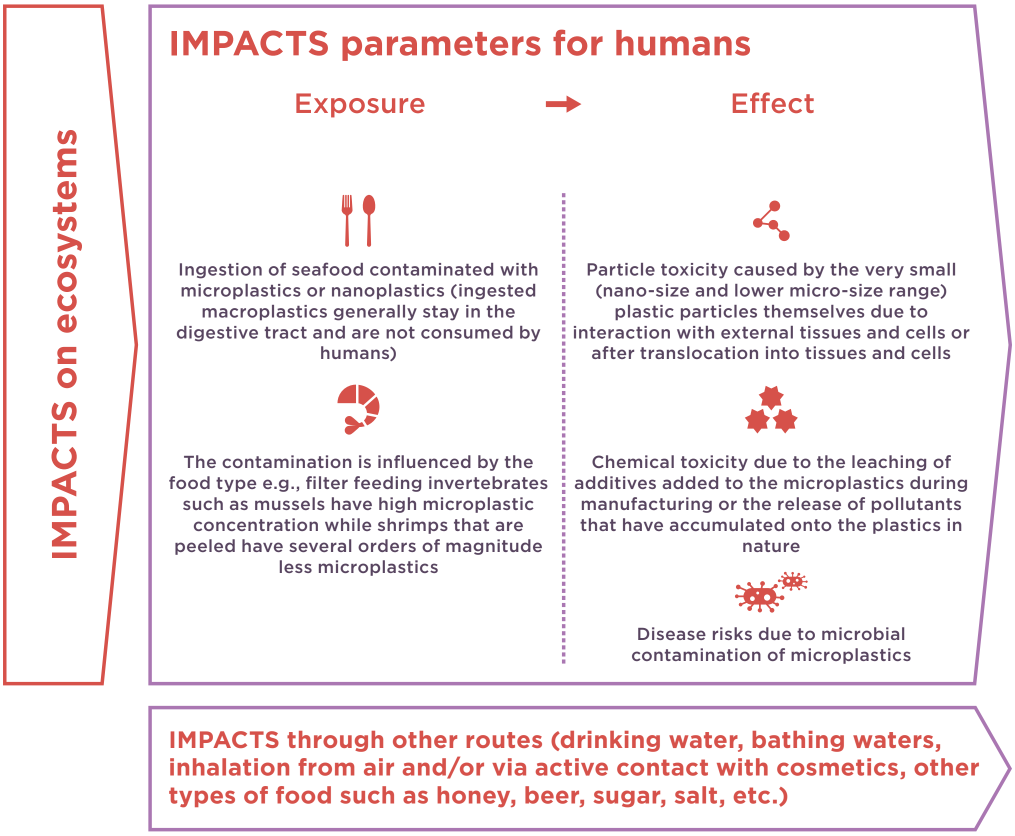


Figure 13. Potential framework to assess the impacts of plastics.

Once marine ecosystems have been impacted by plastics, humans can also be exposed to microplastics and nanoplastics through dietary exposure to contaminated marine foodstuffs, given their high trophic level in the marine food chain. A common unit in LCA to express damage on human health are DALYs (Disability Adjusted Life Years), calculated as the sum of the Years Lost due to Disability (YLD), for people living with the health condition or its consequences, and the Years of Life Lost (YLL) due to premature mortality in the population (WHO, 2019).

Figure 13 summarises the approach and key parameters to derive a potential characterisation factor for the impact of plastics on human health in the future.

4.2.1. Exposure factor

In the case of marine plastic debris, humans are exposed through the ingestion of seafood contaminated with microplastics or nanoplastics. The level of contamination depends on the food, e.g. if the organism is peeled before ingestion.

4.2.2. Effect factor

GESAMP (2016) identified three possible effects of plastic particles on human health:

1. Particle toxicity caused by the very small (nano-sized and lower micro-sized range) plastic particles themselves due to interaction with external tissues and cells or after translocation into tissues and cells.

2. Chemical toxicity due to the leaching of additives used in the manufacture of plastics or the release of pollutants that have accumulated onto the plastics in nature.

3. Disease risks due to microbial contamination of microplastics.

In theory, cumulative effects can occur through particle and chemical toxicity after the particles have been internalised in tissues or through chemical mixture toxicity effects. Other plastic impact pathways such as drinking water are not covered in this report.

In a nutshell

Development of impact assessment methodologies is needed both to:

1. compare the impact of different plastic leakages (e.g. different polymers or different object shapes); and
2. allow for analysis of trade-offs between plastics-related impacts and other potentially severe environmental burdens.

Two areas of protection are foreseen: impacts on ecosystems resulting from both macroplastics and microplastics and the potential impact on human heath resulting from ingestion of contaminated seafood. (Impacts related to the presence of plastics in other compartments of the environment than oceans and waterways have not been discussed in this report.)

Methodologies to assess these impacts are currently lacking. If the theoretical framework and impact pathway seem quite clear, the supporting data (i.e. the fate and characterisation factors) are not available yet.

As a result of this knowledge gap, the use of a plastic leakage inventory indicator should be used to guide decision-making in the short term.

Owing to the high uncertainty related to impact assessment, the development of qualitative approaches could be an option to complement the inventory information without diving into the full complexity of impact assessment. This could be based on different key parameters such as degradation rate, shape or potential toxicity.

In the long run, development of a comprehensive impact assessment method is needed to allow embedding the plastic footprint approach within the LCA framework.

5. Monetary valuation of plastic

Monetary valuation is a complementary methodology to LCA that provides a monetary assessment of environmental impacts, ecosystem services and social capital. Figure 14 shows that while LCA captures the impact of human activities on human health and ecosystems, valuation estimates the effect of natural capital degradation on businesses and society.

Ecosystem goods and services, and the natural capital stocks that produce them, are critical to the functioning of the Earth's life-support system. However, they are not fully 'captured' in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, resulting in the provision of too little weight in policy decisions (Costanza et al., 1997, 2014). It is for this reason that methodologies for monetary valuation of natural capital degradation have been developed.

Several studies have provided estimates of the natural capital valuation of plastics, those with detailed quantitative results are presented in next paragraphs.

An analysis conducted by Trucost for UN Envionment (2014) evaluated the total natural cost of plastics used in the consumer goods industry as US$ 75 billion per annum, of which US$ 13 billion correspond to the cost to marine ecosystems of plastic released into the ocean.

This cost is generated by a range of upstream and downstream environmental impacts. Upstream impacts include those from plastic production and transportation (greenhouse gases, air/land/water pollutants). Downstream impacts include the disposal of plastic after its use and arise from plastic landfilling, incineration, recycling and littering, including impacts on oceans and the loss of valuable resources when plastic waste is sent to landfill rather than being recycled. The most significant upstream impact is greenhouse gas emissions released from producing plastic feedstock, which contribute over 30% of the natural capital costs.

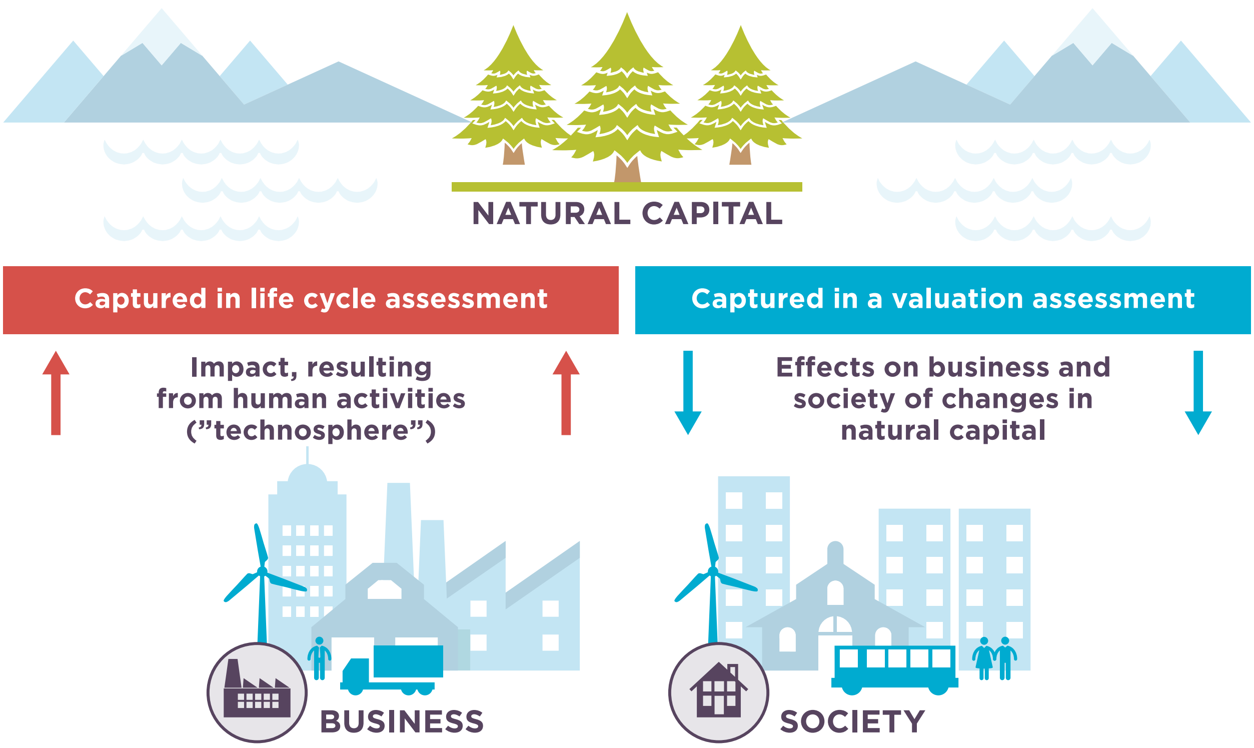


Figure 14. Scope of LCA and valuation assessment.

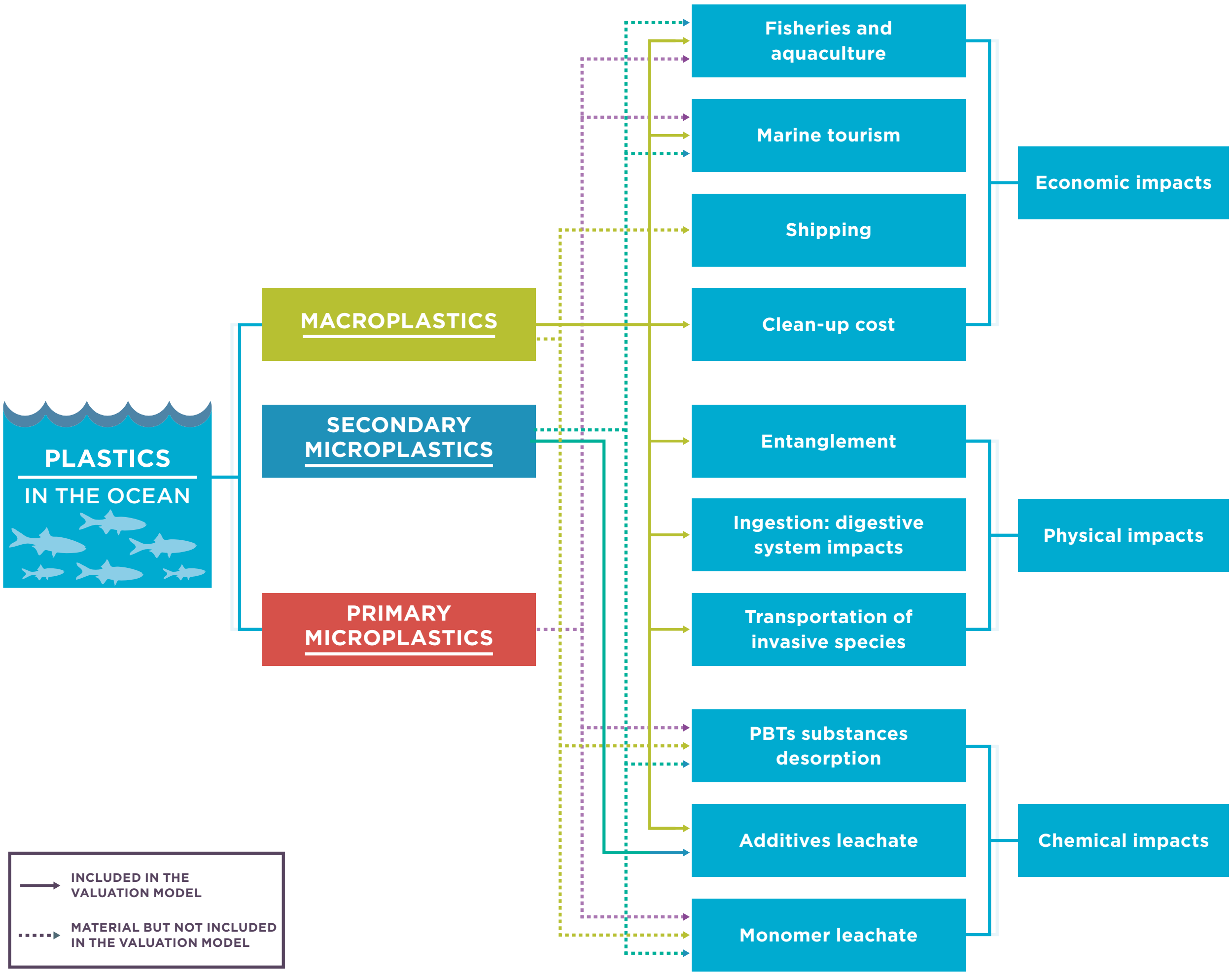


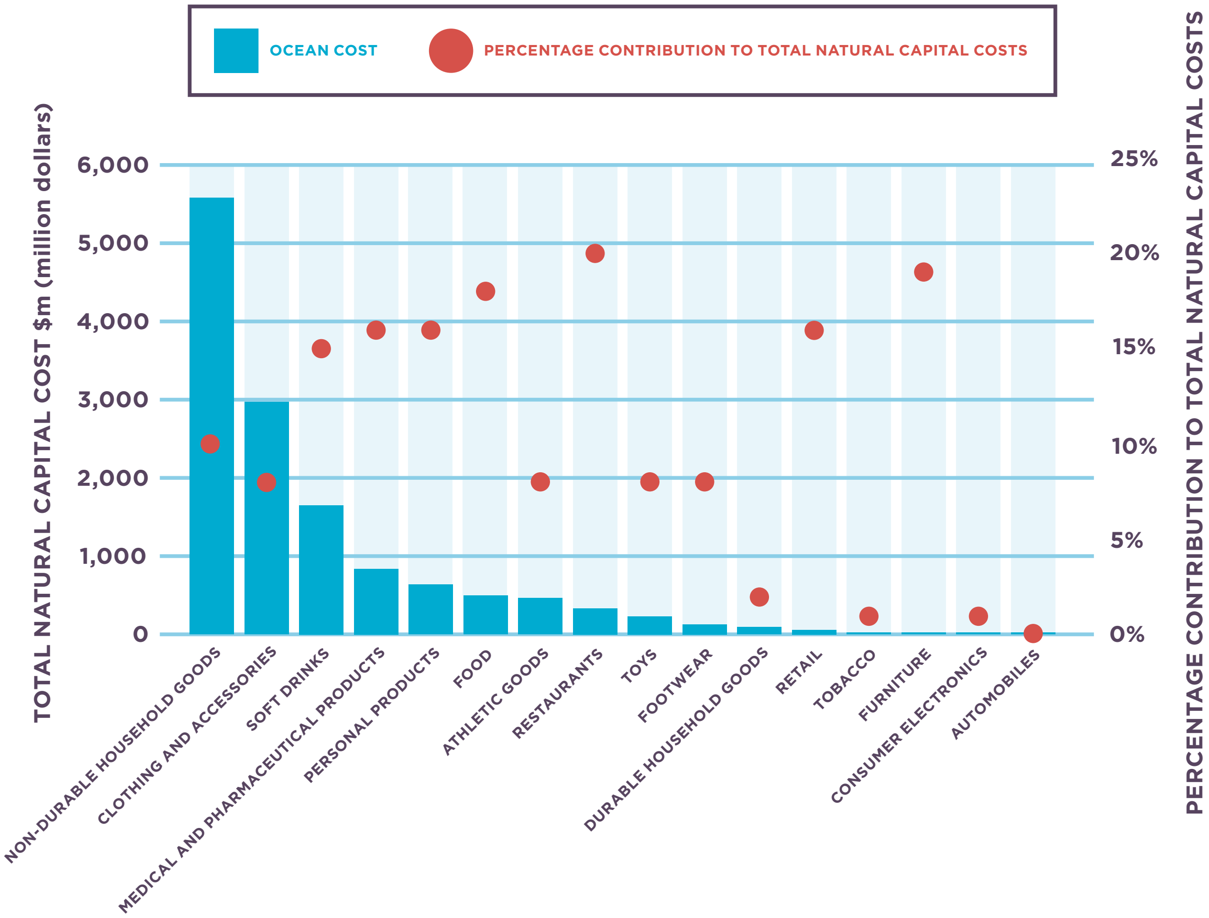
Figure 15. Impact pathways included and excluded from the valuation model (UN Environment, 2014).

According to the Trucost study, the total natural cost to marine ecosystems includes economic losses incurred by fisheries, aquaculture and tourism as well as the entanglement and ingestion impacts on marine species. Figure 15 presents the types of impacts included and excluded from the valuation model.

The natural capital cost was calculated by converting the physical quantities of different types of environmental impacts into a monetary cost and summing them. For example, physical impacts through entanglement and ingestion are estimated through records of different types of species affected among marine mammals, fish and seabirds, combined with a survey on the willingness to pay for the preservation of an ecosystem good or service.

The total natural capital cost of plastic leakages in marine ecosystems by sector is captured in Figure 16. This pathway contributes a non-negligible part of the total end-of-life and total life cycle impacts. On average, the impact of plastic on marine ecosystems accounts for 17% of total life cycle impacts.

A report conducted by Trucost for The American Chemistry Council (ACC) (Lord, 2016) applied the natural capital valuation framework to estimate the value of the environmental costs of plastic and its alternatives. Greenhouse gas emissions, air pollution, land and water pollution, water depletion, ocean impacts and other costs generated throughout the plastics value chain were evaluated. This report was intended as an extension to the previously mentioned Trucost report for UN Environment (UNEP, 2014), examining the sustainability implications of replacing



Total natural capital costs correspond approximately to over 80 million tonnes of plastic. Trucost calculations derived from, but not limited to, World Bank |7|; PlasticsEurope |8|; Eurostat |9|, and the US EPA |10| datasets.

Figure 16. Total natural capital cost of plastic leakage in marine ecosystems by sector (UN Environment, 2014).

plastics with alternatives. The methodology to evaluate environmental costs is similar to that used in the earlier report.

The model to estimate the environmental costs of marine debris has been adapted to consider the quantity of mismanaged waste, and the share that becomes marine debris. However, it only considered the waste generated within 50 km of the coast. Table 2 shows the types of impacts related to marine debris in the ocean.

The environmental cost of plastics is estimated at US$ 139 billion per annum, of which the cost of plastic marine debris generated in the consumer goods sector is estimated at US$ 4.7 billion per annum. (For comparison, the cost of the impacts on climate change is estimated at US$ 71 billion per annum).

There is currently no study covering the environmental cost of primary microplastics, only secondary microplastics which are generated by macroplastics.

Table 2. Types of impacts covered in Plastics and sustainability: a valuation of environmental benefits, costs and opportunities for continuous improvement. Report prepared by Trucost for ACC (Lord, 2016).

Economic Impacts	Economic losses to fisheries, aquaculture and marine tourism. Opportunity costs for volunteers participating in beach clean-up activities.
Chemical Impacts	Damage to human and ecosystem health.
Physical Impacts	Wildlife entrapment and entanglement due to litter, valued in terms of community willingness to pay to prevent these impacts on species.

In a nutshell
Monetary valuation could be a good complement to plastic footprint methodologies, and enable better understanding and management of the trade-off between different environmental impacts. However, monetary valuation will be applicable only when the impact pathway has been modelled and fed with appropriate data.

6. Conclusions, recommendations and ways forward

In this report we have reviewed available plastic footprint methodologies and those currently in development. The main conclusion is that methodologies to appropriately assess how much plastic is leaking into the ocean and how harmful this leakage is for ecosystems and human health are still missing.

- Most existing methodologies focus on assessment of plastic usage, waste or recycling rates.
- Several projects are aiming to develop an inventory approach to assess leakage for both macroplastics and microplastics, but are not yet available for use.
- Although many methodologies are being developed, there is currently no methodology for assessing impacts in a comprehensive manner that allows measurement of trade-offs between different impact categories (for example related to climate and ecosystem damage). Owing to lack of data, most methodologies do not attempt to measure or indicate impacts.

Based on the key findings of this report, and in particular of the review of plastic footprint methodologies, IUCN is working to develop a best-in-class plastic hotspot calculator that can provide key stakeholders across governments, private sector, civil society and academia with data and analysis needed to inform their decision-making on reducing plastic leakage. The work is taking place in collaboration with the scientific community, to develop characterisation factors for assessing environmental impacts. Compatibility between methodologies will help to ensure that, in the long run, addressing plastic pollution does not lead to other unintended consequences.

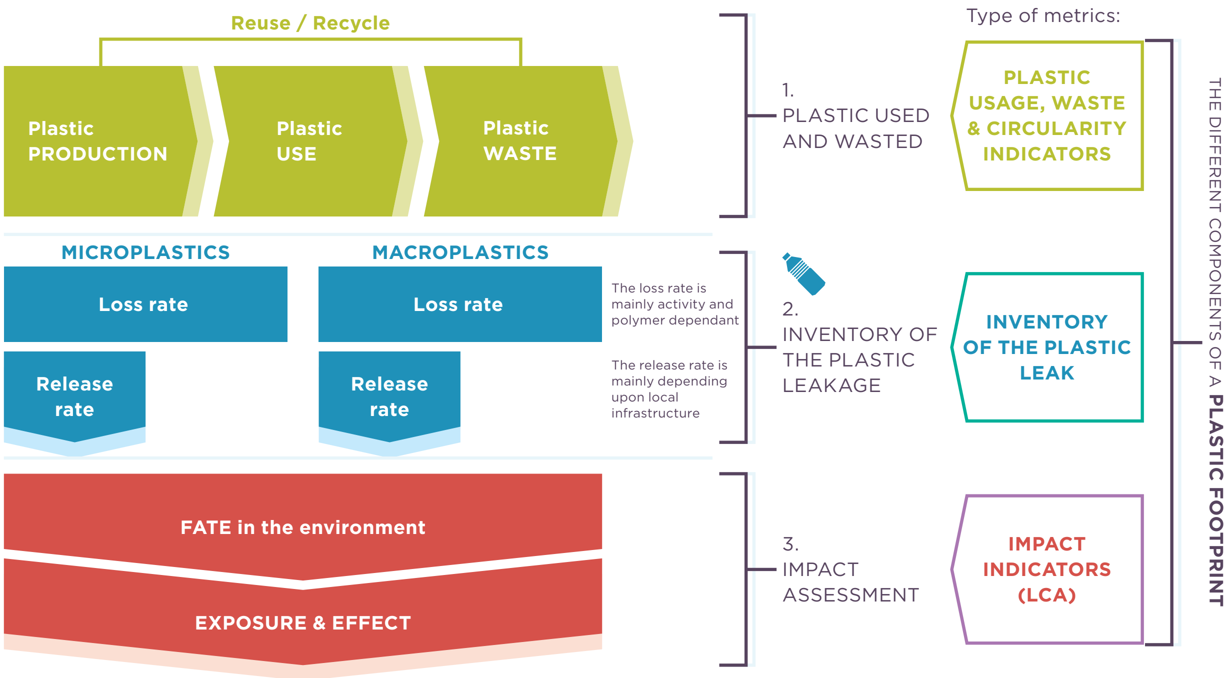


Figure 17. What is included in a plastic footprint?

6.1. A plastic footprint to assess plastic usage, plastic waste and plastic circularity

Although many companies pledge for circularity there are very few recognised metrics to evaluate the level of circularity of a system. The Material Circularity Index developed by the Ellen MacArthur Foundation is an attempt at providing such a metric.

There is a need to reconcile circularity indicators, plastic leakage and the life cycle approach. There is an increasing, and often misguided, debate contrasting LCA with circularity. LCA is criticised for not having accounted for marine plastic pollution and circularity. Circularity, as a concept, is much simpler to understand and is often inappropriately simplified by accounting for recycling rates. In some cases, using a life cycle approach may demonstrate a system with fewer environmental impacts than a circular system. For example, as illustrated in Figure 18, a circular economy scenario encourages material recycling whereas LCA of a material or product may indicate that incineration with energy recovery offers more environmental benefits than material recycling. Such a finding will depend on the material and product as well as the location of the system and the incineration technology. LCA and circularity should be used synergistically to identify the best scenarios in terms of reducing environmental impacts while aiming to maximise circularity.

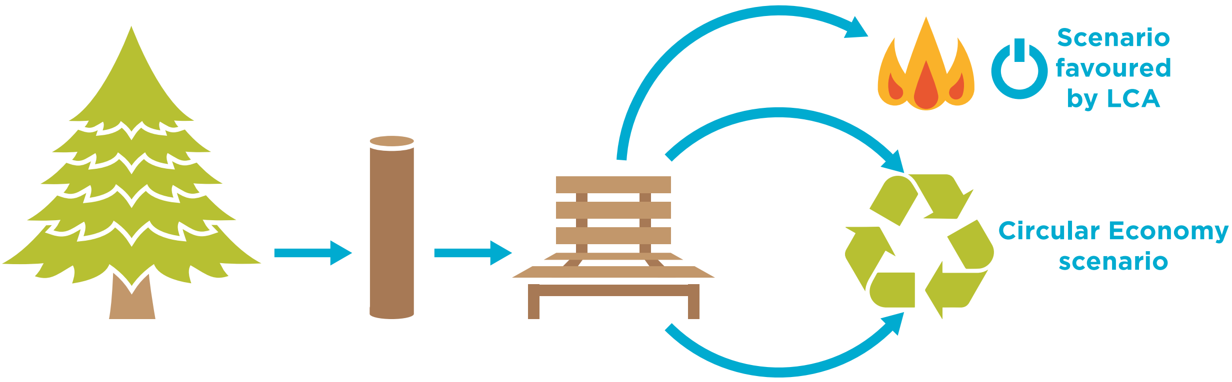


Figure 18. LCA and circularity may lead to different actions (Aoustin et al., 2015).

Circularity indicators would also be relevant to overcome a shortcoming of LCA: to avoid double counting of the environmental benefits between different upstream-downstream systems, LCA accounts only for either the benefits of recycling

In a nutshell
Most companies and countries use plastic quantities or recycling rates as metrics to support decisions and communication. With the exception of the Material Circularity Index, there is no standardised way of measuring circularity. The Material Circularity Index provides interesting insights but seems not to be used at large scale yet by industry.
As a consequence of this,

1. some decisions are based only on the circularity approach and thus may lead to environmental impact trade-offs (e.g. higher carbon footprint); and
2. the problem of primary microplastics is generally disregarded by the private sector.

Way forward

1. Reconcile circularity indicators with the life cycle approach in order to yield more actionable decision support metrics.
2. Encourage stakeholders to switch to leakage/inventory types of metric rather than using only recycling rates as a proxy of their efficiency.

or the benefits of incorporating recycled material. This means that a product or company that does both would not be favoured by LCA, including over another product or company that does one or the other.

The data for evaluation of plastic use are quite readily available from companies and industry associations or from using environmentally extended input-output analysis (EEIOA). However, data related to plastic waste management are not necessarily available, especially for some countries where the informal sector is dominant. The SEA Approach project from the Ellen MacArthur Foundation is in this respect a good attempt to guide data collection and increase the level of understanding of plastic flows at country level.

6.2. A plastic footprint to inventory plastic leakage

When it comes to the inventory of leakage, clear distinctions must be made between plastic pollution from mismanaged waste in the form of macroplastics and the pollution stemming from primary microplastics. This is because the interventions to mitigate these different types of leakage are different.

Inventory of plastic leakage from primary microplastics is easier to model and predict. It is similar to the chemical pollution typically modelled with LCA, with pathway modelling already existing for chemical pollution or needing only slight adaptations.

For primary microplastics, loss rates and release rates for the key sources of microplastics are available in the literature and are on the way to be compiled in the form of usable methodologies (e.g. the "group 2" methodologies listed in Chapter 3 of this report). These generic loss rates allow generic footprinting and ranking different sources against one another. However, more specific loss rates, allowing key parameters determining the leakage to be accounted for are still missing (e.g. influence of polymer type, washing temperature or spinning speed for textile fibre loss). The Plastic Leak Project (see description in Chapter 3) is an attempt to work with industries from different sectors in order to develop these more specific data sets.

Paradoxically, microplastic leakage seems easier to measure than leakage from mismanaged waste, but may be harder to solve due to the very diffuse nature of the sources.

Plastic leakage from mismanaged plastic waste is more challenging to model as it involves behavioural (e.g. littering habits), climatic (e.g. effect of rain or wind on dispersal of waste from dump sites) and geographic (e.g. distance to shore and waterways) aspects. In the case of waste, the loss rate is probably more dependent on the size/weight ratio than on polymer type. Indeed, there is currently no standardised method to calculate a mismanaged waste ratio or a loss rate. Most of the studies use the very generic values published by Jambeck et al. (2015) with original statistics from the World Bank (World Bank, 2012). The loss rate and release rate from mismanaged waste is even more debated in terms of modelling, and supporting data are not available to define specific loss rates for different sizes/shapes of plastic objects or packaging. Loss rates are typically described as varying from 10 to 40%.

More specifically two key elements are missing to properly assess plastic leakage from mismanaged plastic waste:

- Developing better understanding and methods to estimate littering from different geographies; indeed, the quantity littered may be known but only for the fraction collected by municipalities and not the fraction that "falls through the cracks" (i.e. the leakage). This fraction is by definition not measured, and very difficult to "guesstimate". A proxy of littering has been provided by Jambeck et al. (2015), mentioning 2% for all countries.
- Developing a model to assess the loss rate from dumpsites and inappropriately managed landfills is also needed in order to strengthen the currently accepted figure

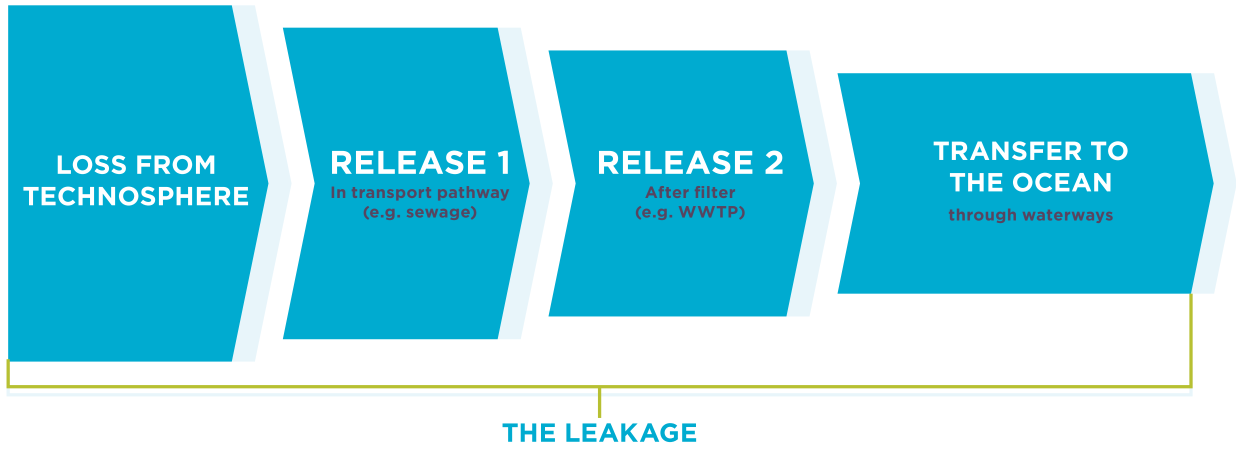


Figure 19. Key stages of the leakage pathway.

of "8 million tonnes of plastic entering the oceans" (Jambeck et al., 2015). The reality might be far from this number.

Three approaches (among others) can be foreseen to address the two points above (i.e. the 2% littering rate and 10-40% loss rate):

1. **Rebuild a loss rate from field data (e.g. plastic found on beaches).** This sounds interesting but introduces a bias in the analysis as plastic found on beaches is only representative of one single component of the leakage (e.g. floating plastic) and is very much dependent on local conditions (e.g. wind patterns).

2. **Correlate the loss rate with the residual value of plastic on the secondary material market, with the rationale that more valuable plastic is less prone to leak from the system.** This approach creates an interesting link with the circular economy.

3. **Correlate the loss rate with some design criteria, e.g. attachment of the lid to the bottle should reduce loss rate.** This approach is interesting as it would allow measurement of the influence of design choices. However, with the current state of knowledge, this approach would introduce considerable subjectivity by requiring expert judgement rather than being supported by evidence from the field.

Assessing leakage from mismanaged waste may require a lot of "guesstimate" work that may distract stakeholders from action priorities. Using circularity indicators may be a reasonable option for action in the short term, while models to refine the leakage pathways are defined.

Release rates are highly dependent on local infrastructure (share of water treatment, combined sewers versus separated, overflows, road run-off infrastructure) as well as climatic (wind) and geographic conditions (distance to shore). The environmental fate transport pathways of macroplastics and microplastics should be better understood. Plastics are lost from the technosphere into the ocean (e.g. mismanaged waste of eroded microplastic particles) in various ways. For example, a transport medium can serve as a carrier (e.g. sewage water, road run-off, or wind-blown) or a potential obstruction or physical barrier (e.g. reverse osmosis treatment).

Another stage of marine release can be between waterways, for example as rivers make their way from inland to the ocean. Current approaches propose to consider the fresh and salt water compartments as a single compartment; this does not distinguish between plastics released into rivers or the ocean. This could be refined further when plastic footprint methodologies have gained more maturity. Recent studies (Unice et al., 2018) on car tyres show that, in the case of the Seine watershed, 49% of road and tyre wear particles reach waterways but only around 2% reach the estuary. Results may be very different

In a nutshell

Performing a generic plastic footprint to inventory and rank different sources of plastic leakage seems to be an achievable goal in the short term. Using the methodology to be more specific and support ecodesign strategies will be more challenging as: (i) more specific emissions factors are needed for microplastics, and (ii) the conceptual framework for waste to leakage modelling is still fragile, making the current estimation of plastic leakage (e.g. the 8 million tonnes figure) questionable.

Ways forward

1. Guide the scientific community in generating the data that are currently missing to feed the models and yield more robust outcomes, e.g. more granular release and littering rates for different plastic applications, in order to set more specific and actionable priorities for action.
2. Launch sectorial working groups with industries, coupling source and pathway stakeholders, in order to develop more specific and actionable emission factors for microplastics.
3. Advance the understanding of the release rate from the lost fraction (e.g. capture rate in waste water treatment plants) and the transport in rivers for plastics of different densities and shapes.
4. Develop a recognised approach to estimate littering rate and loss rate from dumpsite and mismanaged landfills.
5. Use the plastic footprint methodology at the inventory level in conjunction with other impact indicators to support decision-making and ecodesign projects, as long as a robust impact assessment method is not available.

for particles of different density and mobility in freshwater systems.

6.3. A plastic footprint to assess environmental impacts resulting from plastic leakage (LCA)

The fate of macroplastics and microplastics in the environment needs to be better understood. The fate includes the residence time for different types of plastics and in different media. This includes the rate of degradation of macroplastics into microplastics as well as their transfer into different environmental compartments. In this respect the role of industries and plastic producers/converters in providing degradation, fragmentation and biodegradation data for different types of polymer will be key. Standardised testing methods may be needed.

In terms of endpoints, the environmental impacts should fit within the existing LCIA framework without the need to add another. Ecosystem quality and impact on human health are the two areas of protection to consider.

In terms of midpoints, some new indicators may need to be developed, e.g. marine ecotoxicity.

The case of microplastics seems easier to be embedded in the LCA framework, as the impact of macroplastics is more shape dependent than material dependent (e.g. entanglement). Also, the mechanism of entanglement may be seen as different from a toxic effect in terms of pathway modelling.

Impact assessment is the area where the lack of data is most acute, although many studies are under way to provide characterisation factors for different plastics based on ecotoxicity testing.

The fate modelling seems to be the first step to move towards impact assessment. Key questions need to be answered, such as the degradation rate for different polymers in the marine environment, the rate of fragmentation from macroplastics to secondary microplastics, and the duration of potential exposition to organisms. A better understanding of the different compartments where plastics are accumulated is also key.

The current inventory approach considers oceans and freshwater waterways as a whole. In terms of impact assessment, they might have to be considered as two distinct compartments.

Impact assessment could be meaningful if it is polymer/shape specific in order to serve as support for decision-making in product/packaging design for example. Such a specific method is required to guide eco-design approaches. In contrast, impact metrics may only be useful to compare plastics with alternative materials in more general terms or to show the influence of reducing/increasing plastic intensity while monitoring trade-offs between different environmental impacts.

In a nutshell

There is an acute lack of data to allow for impact assessment and to embed plastic impacts within LCA frameworks. Certainly, in the short term, shortcuts must be taken to focus on fate and what is measurable, while understanding the limitations of the methodology.

Plastic footprints currently being developed (Marine Plastic Footprint and Plastic Leak Project) propose to include fate in the calculation of the footprint in order to account for different residence times or biodegradability rates for different plastics. This may lead to the development of a 'plastic equivalent' indicator as already in place for carbon and water footprints, but based on different persistence rates for different plastics in the environment.

Ways forward

1. Develop complete fate modelling.
2. Include fragmentation models to understand residence times of plastics in macro and micro forms, and determine environmental compartments where exposure may happen (e.g. surface and column water).
3. Compile characterisation factors from the scientific community.
4. Identify some low-hanging fruit to test the methodology on one to two impact pathways.
5. Ensure compatibility with conventional LCA frameworks and status quo impact assessment methods such as USEtox[5].

5 www.usetox.org

7. Glossary

This glossary is the result of an iterative consultation process that began during an expert workshop organised by IUCN in June 2018 and continued throughout the development of the current publication. Definitions were reviewed and fine-tuned through the Plastic Leak Project (2019), incorporating feedback from a panel of more than 30 experts.

7.1. Plastic-related definitions

7.1.1. Plastics

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

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

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

7.1.2. Macroplastics

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

Source: Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans : a Global Evaluation of Sources. IUCN https://portals.iucn.org/library/sites/library/files/documents/2017-002.pdf

7.1.3. Microplastics

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

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

7.1.4. Primary microplastics

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

Source: Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans : a Global Evaluation of Sources. IUCN. https://portals.iucn.org/library/sites/library/files/documents/2017-002.pdf

7.1.5. Secondary microplastics

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

Source: Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans : a Global Evaluation of Sources. IUCN https://portals.iucn.org/library/sites/library/files/documents/2017-002.pdf

7.1.6. Nanoplastics

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

Sources:
Lambert, S., Wagner, M., 2016. Characterisation of nanoplastics during the degradation of polystyrene. Chemosphere 145, 265–268. http://dx.doi.org/10.1016/j.chemosphere.2015.11.078
Koelmans A.A., Besseling E., Shim W.J., 2015. Nanoplastics in the Aquatic Environment. Critical Review. In: Bergmann M., Gutow L., Klages M. (eds) Marine Anthropogenic Litter. Springer, Cham. https://doi.org/10.1007/978-3-319-16510-3_12
Gigault J, ter Halle A, Baudrimont M, Pascal PY, Gauffre F, Phi TL, El Hadri H, Grassl B, Reynaud S (2018) Current opinion: What is a nanoplastic? Environmental Pollution 1-5

7.1.7. Polymer

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

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

7.1.8. Additive

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

Release of additives to the surrounding environment is an unwanted process for both the manufacturer and the environment, since loss of additives shortens polymer lifetime, and living organisms are exposed to the released additives.

Sources: Hahladakis, J. N., et al., 2018. An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials 344, 179–199. https://doi.org/10.1016/j.jhazmat.2017.10.014
Teuten, E., 2009. Transport and release of chemicals from plastics to the environment ad to wildlife. Philosophical Transactions of the Royal Society B: Biological Sciences 364, 2027–2045. https://doi:10.1098/rstb.2008.0284.

7.1.9. Thermoplastics

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

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

7.1.10. Thermoset polymer

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

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

7.1.11. Bio-based plastics

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

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

7.1.12. Biodegradable plastics

Biodegradable plastics are a family of plastics that can biodegrade (conversion of materials by micro-organisms to water, carbon dioxide and biomass) in a specific environmental compartment (soil, marine, freshwater,...) or a man made environment (industrial and home composting).

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

7.1.13. Oxo-degradable plastics

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

It is unclear and not shown so far, if this accelerated fragmentation would also accelerate biodegradation. The question is, however, whether in uncontrolled conditions in the open environment, in landfills, or in the marine environment, the plastic fragments will undergo partial or full biodegradation within a reasonable time frame. If this is not the case, oxo-degradable plastic will contribute to the microplastics release in the (marine) environment while misleading consumers. Oxo-degradable plastics should not be considered as biodegradable or compostable plastics. As oxo-materials are mostly conventional polyolefins or PET, they could be explained in connection with conventional plastics or after the bioplastics related topics. EU will most likely ban oxo-plastics in coming years.

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

7.1.14. Compostable plastics

'Composting' is enhanced biodegradation under managed conditions, predominantly characterized by forced aeration and natural heat production resulting from the biological activity taking place inside the material. The resulting output material, compost, contains valuable nutrients and may act as a soil improver.

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

- the packaging material and its relevant organic components (>1 wt.%) are naturally biodegradable;
- disintegration of the packaging material takes place in a composting process for organic waste within a certain time;
- the packaging material has no negative effect on the composting process; and
- the quality of the compost is not negatively influenced by the packaging material.

Sources:
M. van den Oever, Bio-based and biodegradable plastics – Facts and Figures, Rapport nr. 1722, 2010
http://ec.europa.eu/environment/circular-economy/pdf/oxo-plastics.pdf

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

7.1.15. Virgin plastics

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

7.1.16. Recycled plastics

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

7.1.17. SPI codes

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

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

7.1.18. Polyolefins

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

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

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

7.1.19. Single-use plastics

Single-use plastics products include a diverse range of commonly used fast-moving consumer products that are discarded after having been used once for the purpose for which they were provided, are rarely recycled, and are prone to littering.

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

7.1.20. On-the-go plastics

On-the-go plastic items are those consumed while on the move in public spaces, rather than in the home or at cafes and restaurants. This term is used in opposition of in-home used plastics.

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

7.1.21. Tyre and road wear particles

Tyre wear particles are generated from the friction between the tyre and the road. This ensures a sufficient grip on the road and safety. The particles are therefore not simply rubber pieces from the tyre, but an agglomeration of material from the tyre and the road. They are therefore identified as Tyre and Road Wear Particles (TRWP).

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

7.2. Pollution and waste-related definitions

7.2.1. Littering

Littering is the incorrect disposal of small, one-off items, such as: throwing away a cigarette, dropping a crisp packet, or a drink cup. Most of the time these items end-up on the road or sideways. They may or may not be collected by municipal street cleaning.

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

7.2.2. Fly tipping

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

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

7.2.3. Dumping

Dumping is the deliberate disposal of larger quantities of litter in a particular area, that is not controlled. Dumping can be the result of the formal or informal collection sector. This could be anything from a single bag of rubbish to a large sofa to a broken refrigerator.

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

7.2.4. Sanitary landfills

Landfilling is the deliberate disposal of larger quantities of litter in a particular area, that is controlled (waste being covered on a daily basis, as well as the bottom of the landfill designed in a way to avoid spills). Landfilling is mainly the result of a formal collection sector.

7.2.5. Waste-to-energy (WtE)

Waste-to-energy is a waste treatment technique designed to recover energy from waste. Waste is burned to produce heat and/or electricity.

7.2.6. Take-back scheme

A take-back scheme is when firms retrieve products they manufacture from customers at the end of their lives in order to recycle, resell, appropriately dispose or renovate the products.

7.2.7. Leakage, losses and release

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

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

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

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

Source: Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans: a Global Evaluation of Sources. IUCN https://portals.iucn.org/library/sites/library/files/documents/2017-002.pdf

7.2.8. Recycling, upcycling and downcycling

Recycling is when waste materials are converted into new materials for the production of new products. Upcycling is when materials are recycled to produce a higher value or quality product than the original. Downcycling is a recycling process where the value of the recycled material decreases over time, being used in less valued processes, with lesser quality material and with changes in inherent properties, when compared to its original use. Terminology used in different types of plastics recycling and recovery can be found in Table 3.

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

7.2.9. Primary / secondary / tertiary plastics recycling

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

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

7.3. Footprinting-related definitions

7.3.1. Environmental footprint

A total product environmental footprint is a measure of the direct (Scope 1) and indirect (Scopes 2 and 3) pollutant emissions associated with all activities in the product's life cycle. Products are defined as either goods or services. ISO 14044 defines a footprint as, "metric(s) used to report life cycle assessment results addressing an area of concern" and defines area of concern as an "aspect of the natural environment, human health or resources of interest to society".

The direct footprint measures specific impacts created by the firm or any company-owned and company-controlled activities or products. A comprehensive study of all relevant impacts needs the assessment of several impacts, e.g. with a LCA. The indirect footprint measures the impact of many other activities related to the company or product but controlled by third parties. A comprehensive environmental assessment is based on a cradle-to-grave approach

Table 3. Terminology used in different types of plastics recycling and recovery.

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

and considers upstream (suppliers) and downstream (customers) activities of a company."

Sources: https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/carbon-footprint/
International Organisation for Standardisation (2006). 14044:2006 Environmental management -- Life cycle assessment -- Requirements and guidelines

7.3.2. Emission factor

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

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

7.3.3. Life Cycle

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

Source: ISO 14040

7.3.4. Life Cycle Inventory (LCI)

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

Source: ISO 14040

7.3.5. Life Cycle Assessment (LCA)

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

Source: ISO 14040

7.3.6. Life Cycle Impact Assessment (LCIA)

Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product. Impact assessment generally consists in assessing fate, exposure and effect.

Source: ISO 14040

7.3.7. (Elementary) Flow

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

Source: ISO 14040

7.3.8. Environmental impact

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

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

7.3.9. Environmental fate

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

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

7.3.10. Exposure

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

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

7.3.11. Effect

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

7.3.12. Circular economy

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

Source: https://www.ellenmacarthurfoundation.org

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

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

7.3.13. Circularity

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

7.3.14. Value chain

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

7.3.15. Supply chain

The supply chain of a product is the processes involved in its production and distribution. This includes aspects such as material type, material sourcing and transport of products between production stages and from final production to markets.

7.3.16. Foreground system

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

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

7.3.17. Background system

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

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

7.3.18. Net positive impact

Net positive impact is a way of structuring business goals to give back more to society or the environment than the negative impact of the business, thus producing a net positive impact.

7.3.19. Environmental externalities

Environmental externalities refer to the economic concept of uncompensated environmental effects of production and consumption that affect consumer utility and enterprise cost outside the market mechanism. As a consequence of negative externalities, private costs of production tend to be lower than its "social" cost. It is the aim of the "polluter/user-pays" principle to prompt households and enterprises to internalize externalities in their plans and budgets.

Source: Glossary of Environment Statistics, Studies in Methods, Series F, No. 67, United Nations, New York, 1997.

7.3.20. Input-Output (IO) Analysis

Input-Output (IO) analysis is a quantitative macroeconomic technique that represents the interdependencies between different sectors of a national economy or different regional economies. This method is used for estimating the impacts of positive or negative economic shocks and analysing direct and indirect effects throughout an economy.

7.3.21. Environmentally Extended Input-Output Analysis (EEIOA)

Environmentally-Extended Input-Output (EEIO) analysis provides a simple and robust method for evaluating the linkages between economic consumption activities and their environmental impacts, including use of natural resources and emissions of pollutants. EEIO is widely used to evaluate the upstream, consumption-based drivers of downstream environmental impacts and to evaluate the environmental impacts embodied in goods and services that are traded between nations.

Source: Kitzes, J., (2013), An introduction to environmentally-extended input-output analysis. Resources 2013, 2:489-503.

7.3.22. Multi Regional Input-Output (MRIO) table

The Multi-Regional Input-Output (MRIO) tables describe economic structure, inter-industry and inter-regional transactions. MRIO tables cover the whole economic structure of multiple regions and exports and imports within and outside these regions as well as long and complex supply chains.

Source: Kanemoto, K., Murray, J., (2013), What is MRIO: Benefits and Limitations, in The Sustainability Practioner's Guide to Multi-regional input-Output Analysis, Common Ground Publishing, pages 1-9

APPENDIX 1

Current expectations from stakeholders

To evaluate the current perceptions and expectations of the private and public sectors around the issue of plastic pollution, an online survey has been initiated by Quantis and EA prior to this publication. The focus is on assessing the level of perceived urgency as well as whether the current level of understanding of the problem is considered by participants as sufficient to drive sound actions.

As of 11 June 2018, 52 answers were recorded: 92% from companies, 2% from government, 6% from other. Sample members are self-selected volunteers. Voluntary response sample has the advantage of being an inexpensive way to conduct a study as data are very easy to gather. However, the counterpart is that researchers have no control over the make-up of the sample and results tend to over-represent individuals with strong opinions and beliefs on either side of the argument.

Key outcomes from the survey

The infographics (Figures A1.1, A1.2) distributed to the survey respondents capture the main findings of the survey, the main ones being:

- The level of concern of marine pollution is very high amongst respondents. Concern exists both for macro- and micro- pollution.
- Many different sectors are perceived to be implicated in marine plastic pollution, with primary contributors being food and beverages, fishing industry, apparel, cosmetics, and tyres and automotives.
- There is a strong need to know when plastics are the right or wrong choice (it is situational) and a strong desire to identify what leads to litter and to help prevent it from occurring.
- The level of pressure felt from respondents on the issue is high and is increasing over time. Most pressure is felt from the media, followed by internal voices and customers/the public.
- Most respondents have launched internal discussions (65%) or engaged externally (52%), but fewer have altered their product design or operations.
- Most respondents' organizations (73%) are considering changing their policies because of marine plastics pollution concerns. However, most don't feel enabled to understand, measure and communicate on the topic.
- Most (80%) would like to have methods to measure their potential contribution to the pollution. But measuring impacts/harm is not the biggest priority-simply identifying the areas of greatest potential for plastic leakage across the value chain are.
- Most respondents feel like they have influence over the source of plastic leaks.
- A pre-competitive collaboration is appealing to respondents for a variety of reasons. There is interest in either engaging with a network or supporting specific projects.
- Almost 80 % of interviewees feel they are missing adequate metrics to measure their contribution to plastic pollution and set priorities for actions.
- There is a strong perceived need for methods to identify plastic leakage along the value chain (and where geographically it is occurring) over measuring potential impacts of those leakages on environmental and human health.

APPENDIX 2

LCA basics

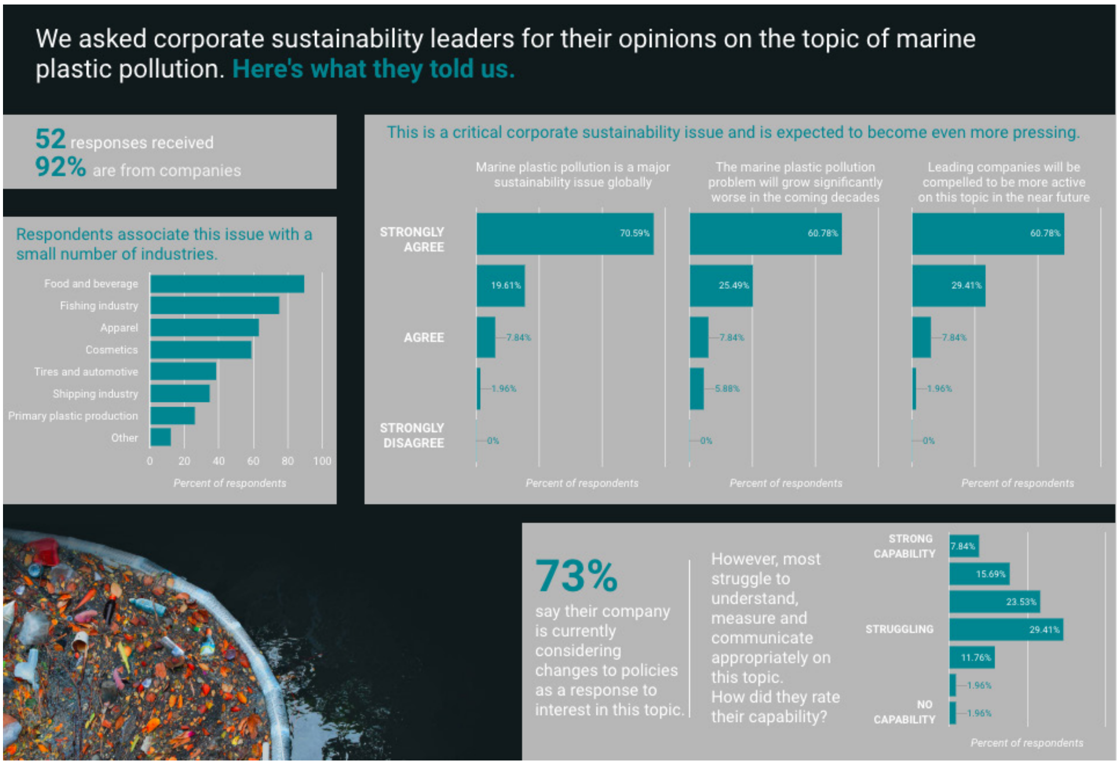


Figure A1.1. Results of the survey (Part 1 - Importance of the Issue).

Figure A1.2. Results of the survey (Part 2 - Maturity of the Company).

Introduction to LCA

Life cycle assessment (LCA) is an internationally recognized approach that evaluates the potential environmental and human health impacts associated with products and services throughout their life cycle, beginning with raw material extraction and including transportation, production, use, and end-of-life treatment. Among other uses, LCA can identify opportunities to improve the environmental performance of products at various points in their life cycle, inform decision-making, and support marketing and communication efforts. LCA is a methodology defined by ISO standards (ISO, 2006a, 2006b).

LCA is a useful tool for understanding the environmental impacts of production processes and the comparison of environmental impacts between different products. It does not cover social challenges such as the erosion of indigenous peoples' rights or poor working conditions. The results assess potential impacts that do not reflect the complexity of real impacts on a local scale. For example, LCA has current limitations to grasp the biodiversity loss caused by natural resources extraction, through human activities such as forestry, fishing and mining. For detailed geographically and spatially explicit impacts evaluation, other tools such as risk assessment or biodiversity inventory are more fit-for-purpose.

LCA is based on four iterative and interconnected stages: 1. goal and scope, 2. life cycle inventory, 3. life cycle impact assessment, and 4. interpretation, as defined in the ISO 14040/44 standards (Figure A2.1). Life Cycle Inventory and impact assessment are the two quantitative stages, as further described in Figure A2.1 below.

Life Cycle Inventory

Life Cycle Inventory (LCI) is the LCA stage where data are collected and various calculations are performed to quantify relevant inputs and outputs to perform an LCA of a product system. For example, for a packaging product, the amount of different materials that are included in the product are required (e.g. amount of different types of plastics, aluminium, paper, etc.) as well as the energy requirements to produce the packaging based on supplied materials (e.g. electricity to produce laminated packaging). At the packaging end-of-life, it is required to know the type of waste management

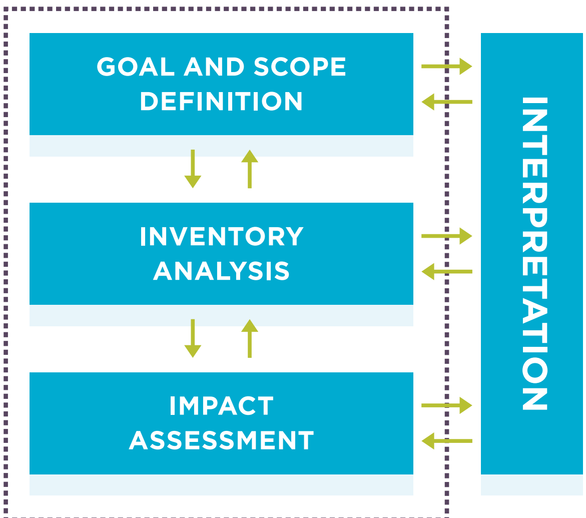


Figure A2.1. LCA 4 stages according to the ISO 14040/44 standard.

(littering, incineration, disposal or recycling) as well as the type and transport distance to the end-of-life treatment facility.

Data for each unit process within the system's boundary can be classified under major headings, including:

- Energy inputs, raw material inputs, ancillary inputs, other physical inputs.
- Products, co-products and waste.
- Emissions to air, discharges to water and soil.
- Other environmental aspects.

Data collection can be a resource-intensive process. The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goals of the study will still be met.

Life Cycle Impact Assessment

Life Cycle Impact Assessment (LCIA) is where an impact indicator is calculated, such as the carbon footprint or the impact on human health. An impact indicator is a class representing environmental issues of concern to which life cycle inventory analysis results may be assigned. LCIA is then done

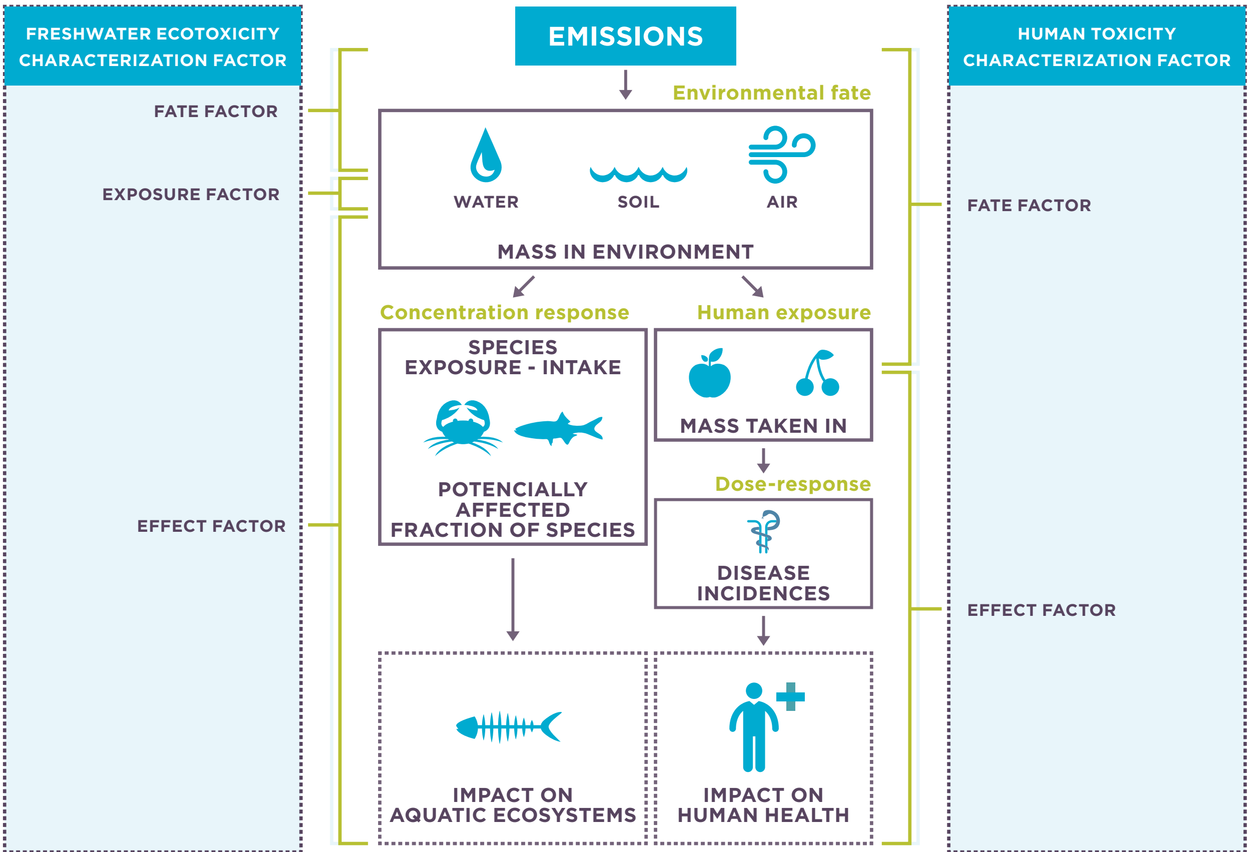


Figure A2.2. Framework for characterizing freshwater ecotoxicity and human toxicity impacts in USEtox 2.0 (adapted from Rosenbaum et al., 2008).

using a weighted summation of the releases of the substances related to a product system with the help of characterization factors, as illustrated in the following equation:

$$IS = \sum_{i} \sum_{x} CF_{x,i} . M_{x,i}$$

Equation A2.1: Impact score calculation.

Where ***IS*** is the impact score (e.g. in kg CO_2-eq for the category global warming), $\boldsymbol{CF_{x,i}}$ is the characterization factor of the substance ***x*** released to compartment ***i*** (e.g., in kg CO_2-eq/kg) and $\boldsymbol{M_{x,i}}$ is the emission of ***x*** to compartment ***i*** (e.g. in kg). For example, when calculating a carbon footprint, the CF of carbon dioxide (CO_2) is 1 kg CO_2 eq and the CF of methane (CH_4) is 28 kg CO_2 eq for a 100-year time horizon according to IPCC (2013).

When focusing on water quality related environmental impacts, the CF is developed based on a cause-effect chain modelled from the emission to the impact of an emitted substance. Water degradation has been classified and streamlined in LCA through impact categories such as aquatic acidification, aquatic eutrophication, human toxicity and aquatic ecotoxicity (Jolliet et al., 2003).

To discuss the impact of marine plastic, several authors use the same reference cause-effect-chain framework as for the latter categories (GESAMP, 2016; Woods et al., 2016). This framework is presented in Figure A2.2, taken from the USEtox model to characterize the impacts related to ecotoxicity and human toxicity of organic and inorganic chemicals (Rosenbaum et al., 2008).

This conventional LCA framework includes different modelling stages, that include the fate factor, the exposure factor and the effect factor. The multiplication of these factors leads to the calculation of a CF, which gives the possibility to quantify the impact of plastic released in the environment.

How to tackle plastic with LCA

Plastic production

During the life cycle of a product, site or service, the impact of plastics is considered mainly through the production, i.e. the energy and material requirements to form a given polymer chain used during the raw material production, manufacturing, packaging and distribution, use or end-of-life stage.

As an example, Figure A2.3 shows the carbon footprint of producing 1 kg of different types of plastics.

Plastic end-of-life

At the polymer end-of-life, the energy and material requirements for its landfilling, recycling or incinerating are considered. The carbon footprint of these different end-of-life treatments for Polyethylene Terephthalate (PET) is presented in Figure A2.4. These results do not consider the benefit of generating heat and electricity from incineration or producing a new bottle from recycling.

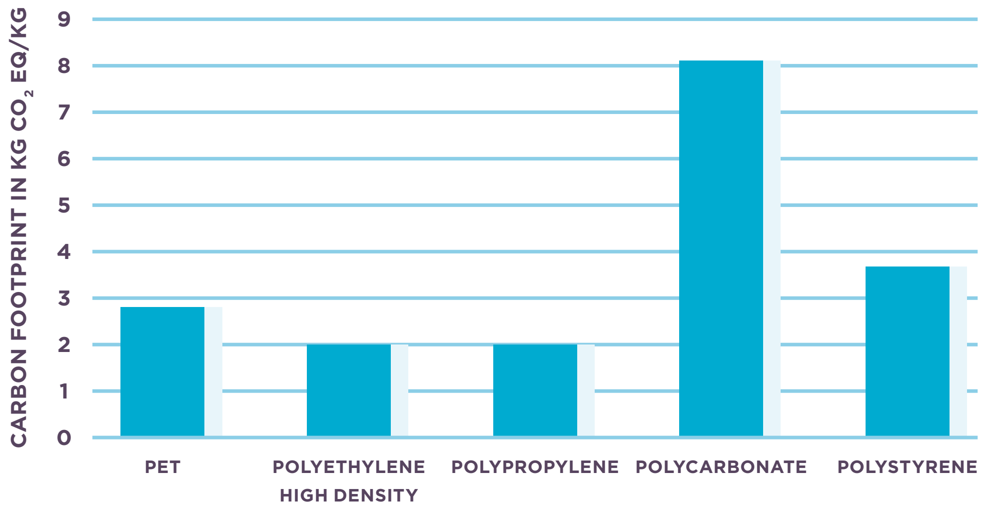


Figure A2.3. Carbon footprint of different types of plastics, calculated based on the ecoinventv3 inventory database with the IPCC 2013 impact assessment method.

In case the plastic does not have a specific end-of-life treatment (because it is littered or disposed in a country with no adequate waste management system), the impact generated on terrestrial, fresh-water or marine ecosystems is not covered in Life Cycle Impact Assessment (LCIA) methodologies. In the same way, the environmental impact of other macroplastics and microplastics lost during a product life cycle is currently missing.

Specific case of recycling

In LCA thinking, recycling induces the benefit of not having to reproduce primary material at the LCI level. For example, for steel, using scrap steel and melting it in an electric converter to produce secondary steel avoids the production of primary steel from iron ore. In the same way, recycling plastic avoids primary plastic production.

There are different ways to consider the benefit of recycling in an LCA study: either the benefit of avoiding the production of primary material is considered at the production stage when secondary material is used, or the benefit of creating secondary material is considered at the material end-of-life. However, a systematic approach should be applied in an LCA study to avoid double-counting the recycling benefits at the material production and end-of-life.

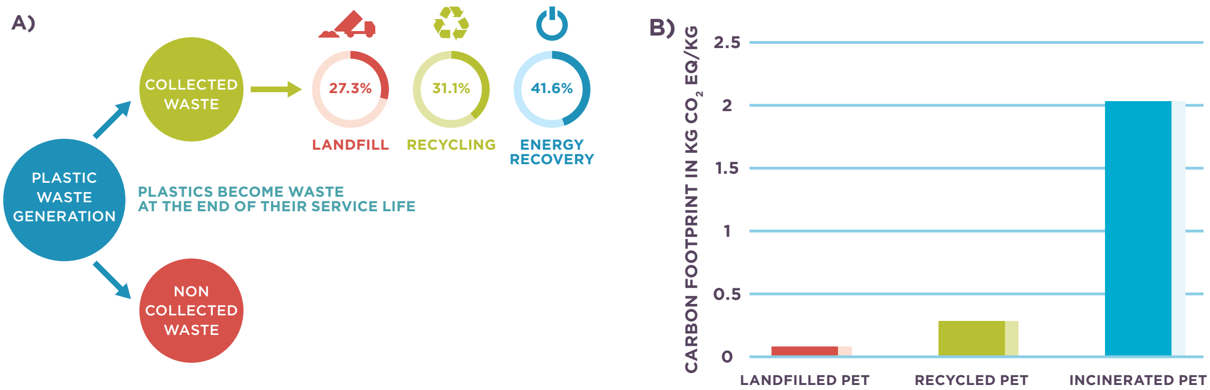


Figure A2.4. A) Fate of collected plastic waste from PlasticsEurope (2017); B) Carbon footprint of PET end-of-life treatments, calculated based on the ecoinventv3 inventory database with the IPCC 2013 impact assessment method.

At the European level, it is recommended to use the so-called circular footprint formula (CFF) developed by the European Commission (European Commission, 2017) as a new standard. This formula takes into account the state of the market for recovered material and balances accordingly the credit in part to the user of the recycled material and in part to the provider of the recyclable material. For example, for secondary materials with high value such as steel or aluminium, the larger part of the benefit is considered when creating secondary material at the end-of-life stage. For secondary materials with low value such as wood or textile, the larger part of the benefit is considered when using secondary material at the production stage. Secondary plastics have an average value on the market, implying that the benefit of secondary plastic is equally spread between the production and end-of-life stage.

Missing pathway for plastic losses

Figure A2.5 illustrates how plastic is tackled in LCA and the missing pathway for plastic losses throughout a company, product, service or site life cycle.

In technical terms, this means that there is no CF at the LCIA level to express the impact of micro- and macro-plastics on humans and ecosystems.

These plastic losses can affect humans and ecosystems through different pathways, including for example inhalation or ingestion by humans. Among these losses taking place during different life cycle stages, part of them will reach the ocean and have an impact on marine ecosystems. In this report, our focus is on pathways related to macro- and micro- plastics that reach the ocean and affect marine ecosystems, which can in turn affect humans through the trophic chain. Yet, no published methodology covers this pathway, given that LCA was originally developed to assess the impacts of land-based industries on mainly terrestrial and freshwater ecosystems.

Figure A2.5. a) Fate of collected plastic waste from PlasticsEurope (2017); b) Carbon footprint of PET end-of-life treatments, calculated based on the ecoinventv3 inventory database with the IPCC 2013 impact assessment method.

APPENDIX 3

Basics and mathematics behind EEIOA

This appendix presents a simplified explanation of the mathematics behind Environmentally Extended Input-Output Analysis (EEIOA) and the main steps of this methodology (Kitzes, 2013; Majeau-Bettez & Maxime, 2015). The example below is based on Majeau-Bettez and Maxime (2015).

The EEIO Analysis includes the following steps:

The compilation and transformation of Supply-Use tables into Input-Output (IO) tables

The Supply-Use tables are usually available from the national statistical offices. They observe and record the different economic activities of a certain region over a certain period of time. For the European countries they are available on the Eurostat website·

The Supply-Use table contains two matrices. Matrix V represents the production (i.e. the supply) of goods and services by each industry. Matrix U represents the use of goods and services by each industry. At national level, the two tables are usually presented in the national currency of the country.

How do Supply-Use tables look?

Example of Matrix/Table V(production):

€	MANUFACTURING INDUSTRY	NUCLEAR INDUSTRY	SOLAR INDUSTRY	SERVICES	TOTAL** Q
MANUFACTURED PRODUCTS	100	0	0	0	100
ELECTRICITY	0	150	50	0	200
SERVICES	0	0	0	150	150
TOTAL* G	100	150	50	150	450

The rows represent the exchanged goods and services in monetary terms
The columns represent the different industries or economic sectors
(*) Total production within each industry: sum each of column
(**) Total production of each product and service: sum each of row

Example of Matrix/Table U (Use):

€	MANUFACTURING INDUSTRY	NUCLEAR INDUSTRY	SOLAR INDUSTRY	SERVICES	FINAL CONSUMPTION (HOUSEHOLDS AND GOVERNMENTS) H	TOTAL Q
MANUFACTURED PRODUCTS	0	15	5	45	100-(15+5+45)= 35	100
ELECTRICITY	30	0	0	30	200-(30+30)= 140	200
SERVICES	0	60	20	0	150-(60+20)= 70	150
ADDED VALUE (OUTPUT-INTERMEDIATE CONSUMPTION), CAN ALSOREPRESENT THE SUM OF WAGES, PROFITS,CAPITAL AND LAND RENT…ETC. (I.E. PAYMENTS TO FACTORS OF PRODUCTION)	100-30=70	150-(15+60)=75	50-(20+5)=25	150-(45+30)=75		
TOTAL* G	100	150	50	150		450

N.B: This is an example of a closed economy, i.e. no imports/exports. See below for more complicated of Supply-Use and IO tables. Consequently, to have equilibrium, one should have:

$$\sum consumption = \sum production$$

How do we interpret Supply & Use tables?

In the above example, the column of the nuclear industry can be interpreted and explained as follows: The nuclear industry produces a total of € 150 of electricity. This production requires €15 of manufactured products, € 60 of services and € 75 of added value. The total production of electricity is € 200 (including € 150 produced by the nuclear industry and € 50 produced by the solar). € 30 of this energy are consumed by the manufacturing industry and € 30 by the services sector. So, the intermediate consumption of electricity is € 60 and the remaining € 140 consists of the final consumption by households and the government/the state.

The two vectors presented above are both calculated twice; once in the Use [U] table and once in the production/supply [V] table. This redundancy in calculation ensures the necessary financial equilibrium between the supply and the demand.

The Supply-Use table is therefore a table that describes the economy as a group of industries or sectors that uses and produces the different goods and services. The next step, which is usually carried out by the statistical offices, is to move to a table that removes details about industries and just shows the interdependence between the different goods and services.

The construct method of a symmetric product-by-product table

This step involves the transformation of the “Supply – Use” table into a symmetric “product-by-product” table. This step usually involves two steps: *(i)* Allocation: when co-production is involved – was not the case in the above example but usually involves certain assumptions (this is an important aspect to check when understanding the differences between the different IO tables), and *(ii)* Aggregation: when the average global technology is calculated for the production of each product (good or service).

An example of transforming the above Supply-Use table into a product-by-product table: Matrix of flows Z

	MANUFACTURED PRODUCTS	ELECTRICITY*	SERVICES**	FINAL CONSUMPTION H	TOTAL SALES X
MANUFACTURED PRODUCTS	0	15+5=20	45	35	100
ELECTRICITY	30	0	30	140	200
SERVICES	0	60+20=80	0	70	150
ADDED VALUE (VA)	100-30=70	200-100=100	150-(45+30)=75		
$\vec{X'}$ TOTAL COST ASSOCIATED TO THE PRODUCTION OF GOODS AND SERVICES	100	200	150		

(*) Note here that there is no distinction between the nuclear and solar industries.
(**) From the above table.

The construction of the matrix of technical coefficients

The matrix of technical coefficients is constructed by normalising the matrix of flows Z with respect to the total production. Each column of this matrix represents the average recipe to the production of the corresponding good or service (Leontief, 1970).

Example of matrix A:

	MANUFACTURED PRODUCTS	ELECTRICITY	SERVICES
MANUFACTURED PRODUCTS	0/100=0	20/200=0.1	45/150=0.3
ELECTRICITY	30/100=0.3	0/200=0	30/150=0.2
SERVICES	0/100=0	80/200=0.4	0/150=0
ADDED VALUE (VA)	70/100=0.7	100/200=0.5	150-(45+30) =75/150=0.5
$\vec{X'}$	100/100=1	200/200=1	150/150=1

How to interpret a column of the matrix A

Example "electricity column": To produce €1 of electricity, we need €0.1 of manufactured goods, €0.4 of services and €0.5 of added value payments to salaries, profits...etc.

The model of quantities in the input-output analysis

In this step, the matrix of technical coefficients A is used to identify what would be the total production of a certain good or service/commodity () to obtain a given level of final consumption ().

Example: How much total production of electricity () is required to meet consumers' final demand of manufactured products of €45 (), €160 of electricity (), and €70 of services ().

To solve this, we need to bear in mind that it does not only depend on the final consumption of, but also on the intermediate consumption required in the production of and The intermediate consumption relies on the technical coefficients, and obtained from the matrix A In other words, how much electricity will be needed in the production process of electricity itself, manufactured products and services? This is expressed formally via the following equation:

$$x_{el} = \underbrace{y_{el}}_{\text{Final consumption}} + \underbrace{a_{el-man}x_{man} + a_{el-el}x_{el} + a_{el-ser}x_{ser}}_{\text{Intermediate Consumption}}$$

Given the above logic, a system of three equations with three unknowns is constructed:

$$x_{man} = y_{man} + a_{man-man}x_{man} + a_{man-el}x_{el} + a_{man-ser}x_{ser}$$

$$x_{el} = y_{el} + a_{el-man}x_{man} + a_{el-el}x_{el} + a_{el-ser}x_{ser}$$

$$x_{ser} = y_{ser} + a_{ser-man}x_{man} + a_{ser-el}x_{el} + a_{ser-ser}x_{ser}$$

In matrix form, this becomes

$$\begin{bmatrix} x_{man} \\ x_{el} \\ x_{ser} \end{bmatrix} = \begin{bmatrix} a_{man-man} & a_{man-el} & a_{man-ser} \\ a_{el-man} & a_{el-el} & a_{el-ser} \\ a_{ser-man} & a_{ser-el} & a_{ser-ser} \end{bmatrix} \begin{bmatrix} x_{man} \\ x_{el} \\ x_{ser} \end{bmatrix} + \begin{bmatrix} y_{man} \\ y_{el} \\ y_{ser} \end{bmatrix}$$

$$\Leftrightarrow \underset{x}{\rightarrow} = \boldsymbol{A} \underset{x}{\rightarrow} + \underset{y}{\rightarrow}$$

$$\begin{aligned} x &= Ax + y \\ x - Ax &= y \\ (I - A)x &= y \\ (I - A)^{-1}x &= (I - A)^{-1}y \\ x &= (I - A)^{-1}y \end{aligned}$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

I is a 3x3 identity matrix,

$L = (I - A)^{-1}$ is what we call the inverse matrix of Leontief.

$$y = \begin{bmatrix} 45 \\ 160 \\ 70 \end{bmatrix}$$

The required final demand

$$A = \begin{bmatrix} 0 & 0.1 & 0.3 \\ 0.3 & 0 & 0.2 \\ 0 & 0.4 & 0 \end{bmatrix}$$

Given the technical coefficients matrix that was obtained using the constructs method from the Use-Supply table:

$$\begin{aligned} x &= (I - A)^{-1} y = Ly \\ &= \begin{bmatrix} 1-0 & 0-0.1 & 0-0.3 \\ 0-0.3 & 1-0 & 0-0.2 \\ 0-0 & 0-0.4 & 1-0 \end{bmatrix}^{-1} \begin{bmatrix} 45 \\ 160 \\ 70 \end{bmatrix} \\ &= \begin{bmatrix} 1 & -0.1 & -0.3 \\ -0.3 & 1 & -0.2 \\ 0 & -0.4 & 1 \end{bmatrix}^{-1} \begin{bmatrix} 45 \\ 160 \\ 70 \end{bmatrix} \\ &= \begin{bmatrix} 1 & -0.1 & -0.3 \\ -0.3 & 1 & -0.2 \\ 0 & -0.4 & 1 \end{bmatrix} \begin{bmatrix} 45 \\ 160 \\ 70 \end{bmatrix} = \begin{bmatrix} 116 \\ 227 \\ 161 \end{bmatrix} \begin{matrix} man \\ el \\ ser \end{matrix} \end{aligned}$$

Extending all the above to the environmental context

A simple IO table as previously explained calculates the total production for a given level of final consumption, i.e. for a given. Similarly, we can use the IO tables to calculate environmental emissions, for example CO_2 and SO_2 emissions, for a given level of final consumption within a certain country.

To be able to do this, a new matrix F is added to the classic IO table.

Emissions and extractions of resources are recorded for each industry as an extension to the Supply-Use tables.

These are then compiled and associated to each product to construct a symmetrical product-by-product table.

The table is then normalised by total production, and should look as follows:

	MANUFACTURED PRODUCTS	ELECTRICITY	SERVICES
MANUFACTURED PRODUCTS	0/100=0	20/200=0.1	45/150=0.3
ELECTRICITY	30/100=0.3	0/200=0	30/150=0.2
SERVICES	0/100=0	80/200=0.4	0/150=0
ADDED VALUE (VA)	70/100=0.7	100/200=0.5	150-(45+30) =75/150=0.5
$\vec{x}'$	100/100=1	200/200=1	150/150=1

Finally, to calculate the total emissions of the life cycle/chain of production of a product/good or service:

We calculate the total production of this product for a given level of final demand ().

The vector of emissions. Total emissions = the product of the matrix of normalized factors of emissions/intensities and the vector of total production of the different goods and services.

$$e = \begin{bmatrix} 0.5 & 5 & 1 \\ 2 & 4 & 0.5 \end{bmatrix} \begin{bmatrix} 116 \\ 227 \\ 161 \end{bmatrix} = \begin{bmatrix} 1353 \\ 1220 \end{bmatrix} \begin{matrix} CO_2 \\ SO_2 \end{matrix}$$

EEIOA for estimating a country's marine plastics footprint

What is included in EEIOA?

The methodologies mobilizing MRIO tables link the financial flows of international trade to their environmental impacts either in terms of emissions of pollutants or resource consumption. Thus, they offer the possibility of modelling the calculation of a footprint on the basis of various possible scenarios affecting the final demand. Such scenarios allow the modelling of the environmental impacts caused by an international trade policy, such as an import taxation or an international trade agreement.

What is not included in EEIOA?

The available MRIO tables cover well developed economies while they deal less systematically with developing countries. Not all of the tables cover the same categories of product or economic sectors or the same countries. The number of economies and sectors can vary greatly from one table to another. Some products can be forgotten by certain tables and some countries can be covered by a generic "rest of the region" or "Rest of the World" (RoW) category.

Moreover, each MRIO table relies on a specific methodology for the aggregation and the harmonization of national data. Thus, the choice of an input-output table for the calculation of a specific footprint depends closely on the objective pursued.

Another limitation of MRIO tables is that they are unable to distinguish between the different production processes within the same category of product.

Figure A3.1. The main MRIO available and their characteristics (adapted from Murray & Lenzen, 2013).

MRIO Databases	Geographical Coverage	Available years/ Frequency	Attribution to a common classification	Number of products	Number of sectors	Number of environmentally satellite accounts	Access
EXIOBASE	43 countries 5 RoW regions	2000 and 2007	ISIC ver.4	200 products 48 types of raw materials	163 industries (sectors)	15 land use types 172 types of water uses	Free
GTAP	244 countries	2004, 2007 and 2011	Agricultural and food sectors: CPC Others: ISIC	57 products	-	CO_2 emissions	Free
Eora	187 countries	1990-2015/ Annual	CPC and ISIC ver.4	Products	26 minimum per country; up to 400 sectors for some countries	35 types Air pollution, Energy use, Greenhouse gas emissions, Water use, Land occupation, N and P emissions, Primary inputs to agriculture (including 172 crops) Human Appropriation of Net Primary Productivity	- Individual country free, - Full Eora free only for academic user
Eora26	187 countries	1990-2015/ Annual	CPC and ISIC ver.4	Products	26		Free
WIOD	43 countries	2000-2014/ Annual	ISIC rev.4	-	56 sectors	Energy use gross, Energy use, emission, CO_2 emissions, emissions to air, units of Energy use, Land use, Material use, Water use	Free

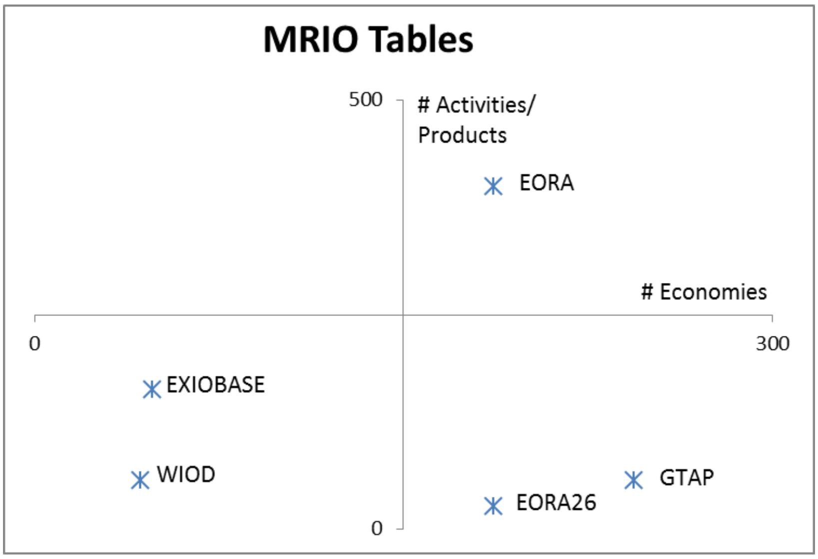


Figure A3.2. Mapping of MRIO tables.

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INTERNATIONAL UNION
FOR CONSERVATION OF NATURE

WORLD HEADQUARTERS
Rue Mauverney 28
1196 Gland
Switzerland
Tel +41 22 999 0000
Fax +41 22 999 0002
www.iucn.org