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Project glossary

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Introduction and objective

This document ("Guiding Document V.1" or "paper" hereafter) is a component of the project Identifying and quantifying plastic contaminant sources and leakages into the aquatic environment[1], executed by UNEP International Environmental Technology Centre (UNEP-IETC) in cooperation with the European Commission Directorate-General for the Environment (DG ENV) and supported by the European Commission.

The main project's objective is to develop a practical methodology to identify and quantify sources of plastic pollution in the aquatic environment, allowing the production of an inventory of plastic pollution from a plastic waste source perspective, so that decisionmakers and control bodies can better understand current scenarios and develop strategies to address plastic pollution, with a particular interest on aquatic environments and focus on tailored actions according to pollution sources. The priority on sources of plastic pollution in aquatic environments is because there are many models and information available on this regard, including environmental aspects like riverine fluxes of plastic pollutants to coastal environments.

This Guiding Document (V.1) has been built upon the Scoping Document that introduced the initial conceptual framework for the toolkit development, aiming to set the model for the establishment of its boundaries and provide a technical basis for the toolkit. The boundaries presented in the previous Scoping Document have been adjusted taking into consideration suggestions and recommendation from the Working group Experts. These concepts, approaches and scope could also be updated in next steps, as the toolkit evolves based on the available data and information.

One of the main objectives of this Guiding Document is to present a first proposal of emission/leakage factors for some of the proposed sectors and activities.

Mains Changes

This Guiding Document adds a set of changes based on the suggestions and recommendations of WG experts made on the previous Scoping Document. Some of the most relevant are:

- General Additions and replacements according to experts' suggestions.
- Comments and clarifications have been added to the conceptual framework and references to monitoring. A new diagram explaining the dynamics of plastics according to the comments received.
- According to comments and recommendations, the categories "Other sectors and households" have been reshaped into two main subcategories: One called "Plastic Use in Selected Sectors/Activities" which addresses Leakages during overall activities: Agriculture and Fisheries; Mining, Construction, and around the title "Diffuse Pollution" a series of phenomena related to Leakages during Tire Abrasion, Open Burning and other phenomena (leakage from Paint and Urban

[1] https://www.unep.org/ietc/what-we-do/plastic-waste-management/eu-funded-project-sustainable-plastic-waste-management

Dust). It is important to highlight that most plastic leakages in these activities run directly into the environment without intermediate processes.

- The presentation of a first set of reference values and coefficients to construct emission factors for the proposed source sectors. For this purpose, in this document we make a first proposal of these values (potentially called "emissions/leakage factors") for the Solid Waste Management and Recovery sectors. These coefficients are included as an annex to the base document.
- Synthesis of a Source to Sea approach
- New Work Plan (as an annex)

It is relevant to note that, in this new revision process, experts keep providing their insights and reinforcing views that may not have been completely captured in this new document.

Note for reviewers

Reviewers are encouraged to comment specially on suggested and potential methods/methodologies that can be suitable for each proposed source. Complementary, we very much appreciate your insights on the accuracy and completeness of scientific, technical and socioeconomic contents in this paper, including the document's structure, its clarity and overall narrative flow.

In addition, we expect reviewers to:

- *suggest specific remedies for identified shortcomings of the Guiding Document ;*
- *point out other priority, emerging and cross-cutting issues or evidence which may not have been highlighted but would be considered a serious omission if these were left out of the final toolkit;*
- *include details of appropriate sources/references that should be considered, added or put in replacement of referred sources;*
- *point out any errors, inconsistencies and/or contradictions of facts/data within and across different sections/chapters;*
- *point out non-essential material that could be deleted, with explanations if appropriate.*

As general instructions for your review, please note:

1. *You may choose to provide a general review in the document or pick only sections and topics within your areas of knowledge;*
2. *Feel free to send your comments either attached to the text or in the accompanying Excel document;*
3. *Please refrain from directly modifying the original text, unless you unequivocally spot an error (technical, not grammatical) that can be corrected with a minor adjustment;*
4. *If you want to propose major changes in the text, please suggest the excerpt in the comments or in a separated file or email;*

5. *Please refrain from commenting on grammar, spelling, terms used or punctuation, unless it affects the meaning or clarity of the narrative. These editing aspects will be dealt with at a later stage;*
6. *Please refrain from adding comments that simply agree with the document; rather, please provide constructive comments that can develop it further.*

Finally, please do not cite or quote this Guiding Document V.1 in any instance out of the context of this review. Opinions and comments in this report, from either writers and reviewers, do not imply any kind of endorsement from UNEP or European Commission.

The authors.

1. Presentation of the envisaged toolkit

While it is a fact that there exists a wealth of methodological approaches to plastic pollution modelling nowadays,[2] these models require data and information that cannot be easily obtained or that needs estimate using the same or other models, such as hydrological models.

On many occasions, these models require large budgets or skilled experts (most cases model developers) to be run, and calculation algorithms are not known to users, who may see this as black boxes of input and output information. Hence, model application has not rolled out in many countries, except when donors and international organisations bring their own models and resources; while there is an overall consensus in the scientific community about the necessity of models with higher levels of granularity and able to identify the locations (sectors) where plastic pollution is happening.[3]

To address this, the project aims to develop an easily applicable methodology to identify sources and estimate plastic pollution from sources, without relying on complicated physical models or data and information that cannot be easily obtained.

Under this vision, the toolkit aims to incorporate some central analytical elements, to render an innovative yet practical methodology, able to provide a comprehensive perspective of sources of plastic pollution and contribution of each part to the plastic value chain, from production to end-of-life.

Technical iterations among WG members and the project team will guide this endeavour, which was formally initiated with a technical meeting (WG meeting) in September 2024[4]. This document reflects the main findings and outcomes from those conversations and the interaction related to the Scoping Document previously shared.

In the following paragraphs the main elements concerning the proposed methodology are outlined, in addition to other factors and principles worth mentioning. Then, chapter two addresses the source categories with some changes and proposal of new sectors, with a brief description around the dynamics of plastic in each category and systematization of potential sources of plastic pollution, which may underpin the development of leakage factors[5].

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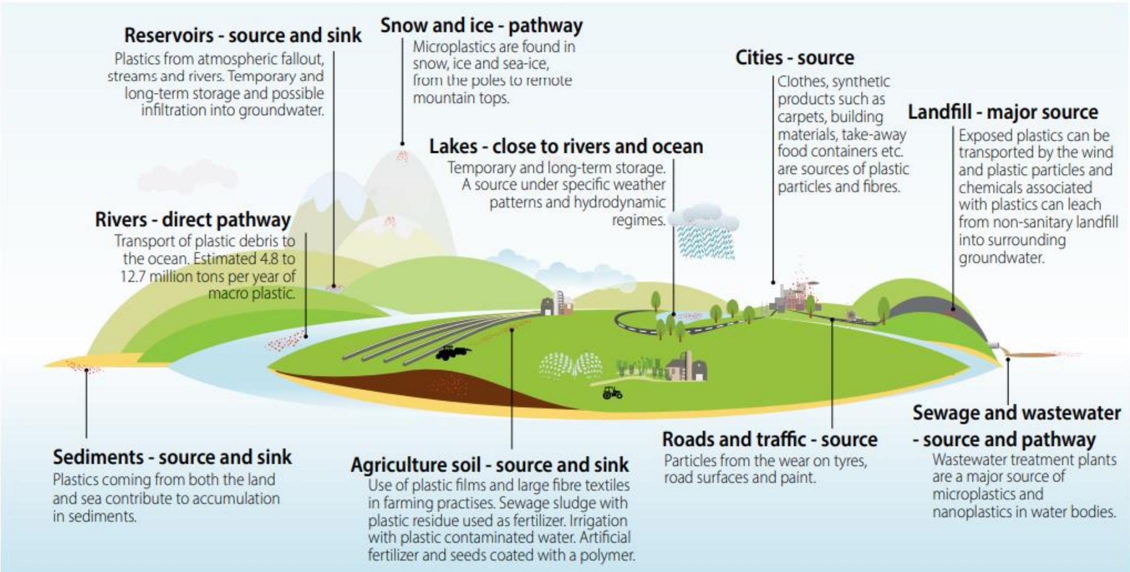
[2] A project's baseline study conducted a literature review on current plastic waste evaluation methodologies and investigated 18 methodologies out of a range of models and tools.
[3] https://www.nature.com/articles/s41586-024-07758-6
[4] https://www.unep.org/ietc/events/working-group-meeting/1st-working-group-meeting-unepec-project-identifying-and-quantifying
[5] For the purposes of this document, we may use the term "plastic leakages" to refer generally to plastic that reaches the environment from the different stages that make up the plastic value chain, and "leakage factors" to refer to the envisaged coefficients to estimate plastic pollution. These nominations may be modified after iterations amid the review processes.

1.1 Rationale

The UNEP report on global assessment of marine litter as plastic pollution[6] discusses the plastic and other classes of pollution in marine environments, and identifies sources of such pollution, yet with focus only on the waste sector and some specific parts of the value chain (Figure 1). Notwithstanding, results of material flow analysis indicate that plastic also leaks in the upstream part of the value chain -production, supply chain, recycling-, suggesting how much plastic is leaking from these sources to nature, through the environmental pathways.[7] As part of monitoring efforts addressing plastic pollution in the marine environment, pollution hotspots[8] have been identified, and to mitigate and avert this, it is essential to address the drivers of the phenomenon -sources of plastic pollution-, as predicated by Nielsen at al. (2019):[9]

> *"As more integrated policy responses to the multiple facets of the plastics crisis start to gain traction, we are likely to see attention move further up the life cycle, and it will be less common to focus on pollution in isolation from other flows."*

Figure 1 - Major sources and pathways of human generated plastic waste in the marine environment



Source: UNEP 2021;

The underlining problem is that, as discussed above, given the complexity of plastic pollution with diverse sources, multiple pathways as well as a variety of plastic polymer types, there has not been an existing tool able to identify and quantify sources and leakages of plastic running to aquatic environments, which can be practically applied

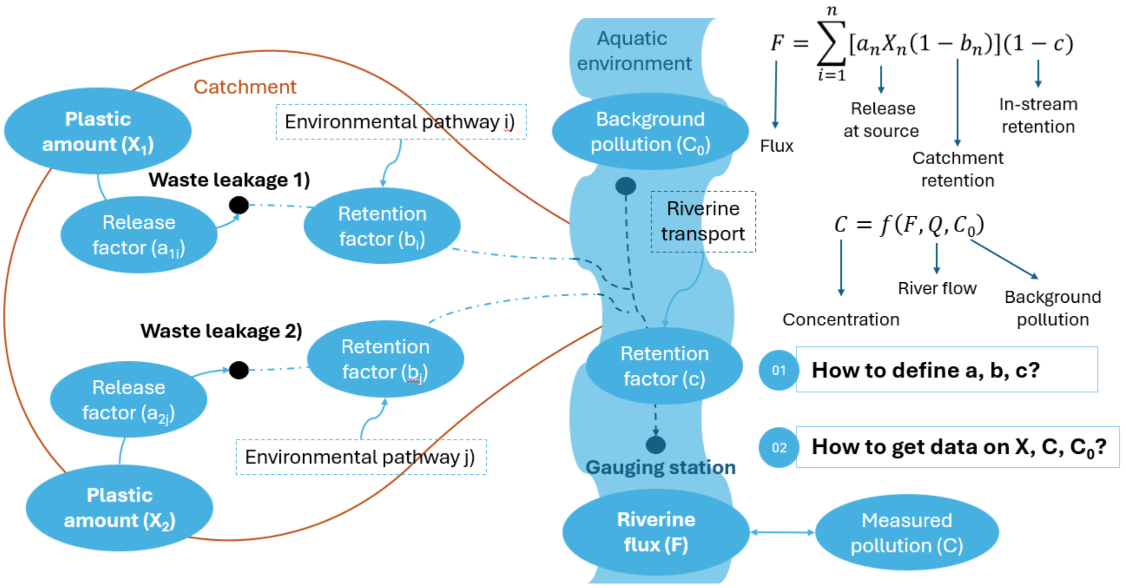
[6] From Pollution to Solution: A global assessment of marine litter and plastic pollution.
[7] https://publik.tuwien.ac.at/files/PubDat_229081.pdf; https://documents1.worldbank.org/curated/en/099515103152238081/pdf/P17099409744b50fc09e7208a58cb52ae8a.pdf
[8] The delineation of hotspots varies considerably across plastic pollution studies. Here it's referred as geographical regions where plastic pollution severely affects the quality and functioning of ecosystems, leading to negative impacts on human health. https://www.sciencedirect.com/science/article/pii/S0048969724034417
[9] https://wires.onlinelibrary.wiley.com/doi/10.1002/wene.360

without relying on physical models and complex algorithms and which can be used to assess plastic pollution sources in a comprehensive manner.

If plastic pollution is framed as a systemic problem requiring larger, systemic and social shifts, it will render a completely different set of solutions compared to predominantly framing it as a waste management problem.[10] One alternative to address this could be an empirical analysis looking at the dynamics of plastic pollution in the environment vis-à-vis socioeconomical aspects of the plastic value chain leading to the phenomenon (of plastic pollution).

Figure 2 schematizes this. The diagram presents a conceptual framework for understanding how plastic pollution enters and moves through natural aquatic systems via different pathways, where a hypothetical plastic waste source within a river catchment is delineated.

Figure 2 – Schematization of the dynamics of plastic waste generation within a river catchment



Developed by Adam Kovacs

The phenomenon may begin in the catchment area, where plastics originate from various sources, (for example through improper disposal, illegal dumping, or leaks in waste management systems). Only a portion of this plastic makes its way into the environment, determined by release/emission factors (a_i), while some remain trapped in soils, vegetation, or urban infrastructure due to retention factors (b_i).

Once plastic escapes the catchment area, it finds its way into rivers, lakes, or coastal waters via different environmental pathways such as stormwater drains, surface runoff, or wind dispersal. However, these water bodies are not pristine; they often contain

[10] https://doi.org/10.1007/978-3-030-78627-4_11

background pollution (C_0), meaning plastic is already present before new pollution arrives.

As plastics travel through river systems, they are subject to additional retention mechanisms. Some particles settle in riverbeds, get caught in vegetation, or accumulate in sediments, governed by an in-stream retention factor (c). The remaining plastic continues its journey downstream, carried by river flow (Q) and shaped by hydrological and environmental conditions. The amount of pollution transported at any given moment, known as flux (F), depends on a combination of these factors.

At the end of this process, plastic pollution could be measured at a gauging station. The concentration of plastic (C) observed in the river is therefore the result of multiple interacting forces: the initial plastic input (X), the retention factors (b, c), and the transport mechanisms (F, Q). The relationship among these elements can be captured in the equation $C = f(F, Q, C_0)$, illustrating how pollution levels are determined by river flux, pre-existing contamination, and water movement.

Understanding this system requires answering two critical questions: How can we accurately define the release/emission and retention factors that dictate plastic movement? And how can we obtain reliable data on plastic quantities, pollution levels, and background contamination? Addressing these questions involves field studies, environmental monitoring, and hydrological modeling, providing the foundation for more effective interventions against plastic pollution.

1.2 Shaping the model

The above conceptualization denotes the identification and quantification of sources of plastic pollution as one of the elements explaining plastic pollution. Analogously, it is widely recognized that until now there has been no methodology capable of identifying and quantifying the sources and amounts of plastic emissions into the environment, from a value chain perspective.[11]

This proposal stands on the grounds that it is possible to develop a practical toolkit to address this, which is science-based yet without relying too much on complex models and algorithms, and which can be used to assess plastic pollution sources in a comprehensive manner. The existence of sufficient scientific basis and the interest of countries in having such information are two further assumptions backing this hypothesis.

Against this backdrop, there was a broad consensus in the WG meeting that the development of plastic pollution inventories should be the best approach to render such information, and it was likewise identified that plastic pollution emission factors for each component of the plastic value chain would likely be the best choice as central analytical elements. Several studies adopted similar approaches to identify sources or estimate quantities of plastic pollution or plastic waste being generated[12], which somehow validates this proposition.

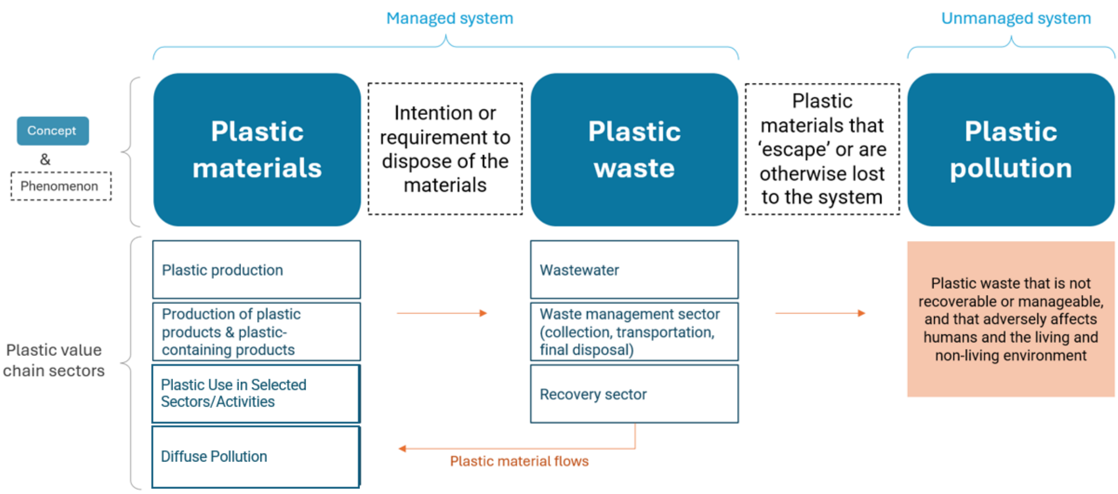
[11] This was one of the inferences most participants of the WG meeting agreed upon, during the 1st Working Group Meeting in Sept/2024.
[12] https://www.sciencedirect.com/science/article/pii/S0048969724046394?via%3Dihub; https://www.iges.or.jp/en/publication_documents/pub/policyreport/en/12696/Plastics_Value_Chain_fin_230424.pdf

Under this configuration, the model should be able to render output numbers of plastic pollution from empirical information for each pollution source, as a useful and practical piece of evidence for policymaking[13]. For this, a primary requirement was the establishment of clear frontiers denoting what the model wants to address.

1.3 Boundaries of the toolkit

Current estimates point that most of plastic pollution found in marine environments comes from land-based sources[14]. Despite having aquatic environments as the ultimate analysis subject under the project, this toolkit will initially consider all sources of plastic pollution, either land- or water-based.

Figure 3 – Differentiation of plastic materials, plastic waste and plastic pollution



Developed by the project team, based on UNECE[17] and UNEP[18]

A first necessary task is a consistent definition about the moment plastic materials become plastic waste, and the moment plastic waste becomes plastic pollution. Figure 3 denotes our proposed approach, which follows UNECE[15] by assuming that plastic materials are considered to become waste when there is an "intention or requirement of holders to dispose of the materials" -when plastics reach their end-of-life.

In turn, plastic pollution refers to the negative effects and emissions resulting from the production and consumption of plastic materials and products across their entire life cycle. This includes waste that is mismanaged (e.g. open-burned and dumped in uncontrolled dumpsites) or which leakage from the system and/or accumulation outside the system can adversely affect humans and the living and non-living environment[16] -this is also represented in the subsequent Figure 4, where the purple arrows depict the moment plastic materials leave the managed system towards nature.

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[13] As the toolkit development advances, there will be discussions around the best platform/software to host such toolkit, including aspects such as interface, usability and data management.
[14] IUCN
[15] https://unece.org/statistics/publications/conference-european-statisticians-framework-waste-statistics
[16] https://www.unep.org/resources/turning-off-tap-end-plastic-pollution-create-circular-economy

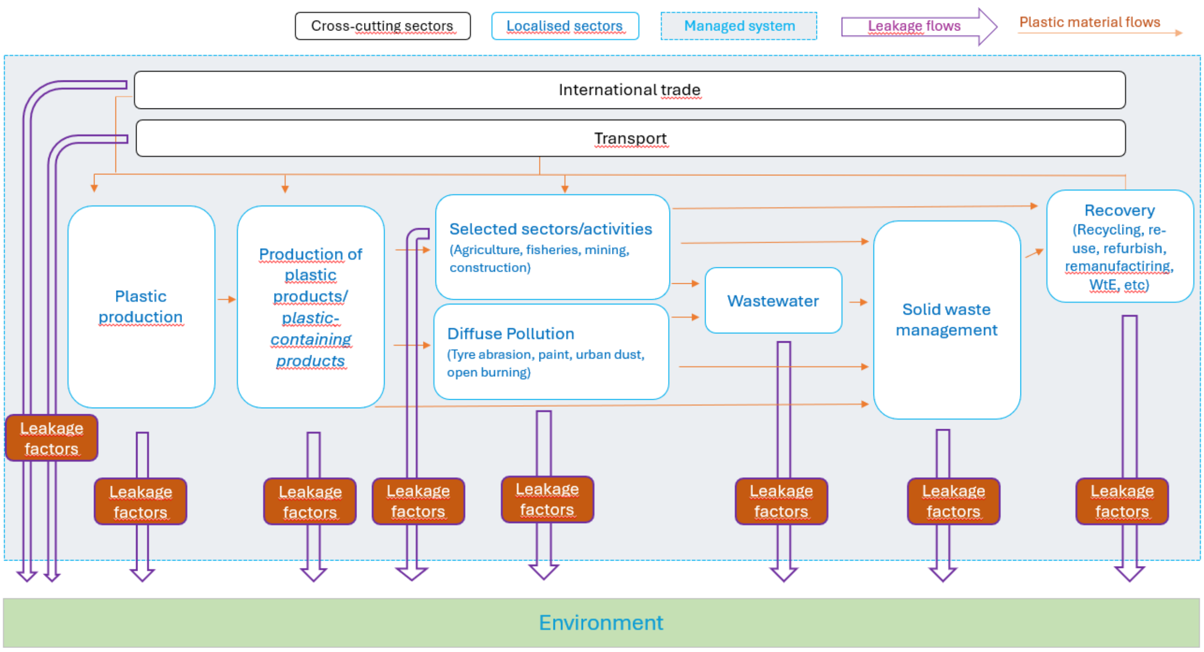
Figure 4 is a further representation of our conceptual framework, analogous to Figure 2 but from a plastic pollution source perspective, where information on the flow of plastic materials between source categories and from source categories to nature (leakage) is also represented.

This scheme is useful to understand the boundaries we want to draw to the model, as it denotes the socio-economic sectors related to the plastics life cycle, differentiating transversal (cross-cutting) from static (localised) sectors. The former refers to activities with no easy and/or simple identification of spatial location, due to the dynamics of the activities per se; whereas the latter concerns to sector where activities can be associated to a specific location or specific facilities, infrastructures -although these may likewise present some cases of diffuse boundaries.

Environment,[17] in turn, is depicted as an external component to the managed system. This element represents natural systems that have low or no interference of humans and their activities,[18] including forests, remote areas, deserts, rivers, and the ocean.

Figure 4 – The toolkit's conceptual framework from a plastic pollution source perspective

Developed by the project team.



Trade and transport represent socio-economic activities and can also be considered sources of plastic pollution. However, as international trade and transport involve multiple jurisdictions, variable economic incentives, and diverse regulatory standards, we consider these factors could introduce a higher degree of complexity and uncertainty that is difficult to capture with a single set of coefficients. In this sense, our model representation considers these categories as extrinsic elements due to their cross-

[17] We are initially proposing the term "Environment" to refer to everything that is outside the "managed system". This definition was adopted after several comments from WG experts.

[18] Jacobson et al. provides a useful framework in this regard, highlighting that 56% of the terrestrial surface can be classified as having low human impact. This includes various natural environments such as forests, deserts, and rivers, which align with the concept of nature being an external component to managed systems. https://doi.org/10.1038/s41598-019-50558-6

sectional nature (interconnected with all sectors in a wide variety of ways) and spatial dynamics (normally leakage points cannot be easily linked to a specific location).

By narrowing our focus to national phenomena, the toolkit may remain easier to calibrate against local/national data sources. In this context, and considering the discussions during the WG meeting, (at least at this stage) these two sectors will be considered apart from the categories of plastic pollution initially mapped for the toolkit.

1.4 Source categories

The rationale for the designation of the source categories was based on the dynamics of plastic material flows within each stage of the plastic value chain (plastic production plastic consumption, plastic use in selected sectors/activities, and plastic waste management, including recovery sector)[19], as well as the different actors involved in each component. To illustrate this, we can refer to "plastic production" and "production of plastic products and plastic-containing products": both the sectors are under the production phase, yet the former has petrochemical companies as main actors, while in the latter plastic converters and assemblers are also important players within the stage.

As a differentiated approach and based on the suggestions received, we propose to group specific sectors and activities with a high level of relevance in the emission of plastics directly into the environment into two large groups: One called "Plastic Use in Selected Sectors/Activities" which addresses Leakages during overall activities: Agriculture and Fisheries; Mining, Construction. In parallel, we group around the title "Diffuse Pollution" a series of phenomena related to Leakages during Tire Abrasion, Open Burning and other phenomena (leakage from Paint and Urban Dust). It is important to highlight that most plastic leakages in these activities run directly into the environment without intermediate processes (as explained in the previous section).

Table 1 – Categorization of the source categories

Plastic value chain sector (source categories)	How plastic pollution occurs	Main actors
Plastic production	Leakages during production and inadequate/illegal disposal	Petrochemicals
Production of plastic products and plastic-containing products	Leakages during production and inadequate/illegal disposal	Petrochemicals, converters, assemblers, etc.
Plastic Use in Selected Sectors/Activities	Leakages during overall activities: Agriculture and Fisheries; Mining, Construction. Littering and leakages not covered by wastewater and waste management systems	Agriculture, fisheries, Mining and Construction sectors, etc.
Diffuse Pollution	Leakages during Tire Abrasion, Open Burning and other phenomena (leakage from Paint and Urban Dust)	Transportation and automotive companies, etc.

[19]Adapted from UNEP/UNITAR's Statistical guideline on measuring flows of plastic along the lifecycle https://www.iges.or.jp/en/publication_documents/pub/policyreport/en/12696/Plastics_Value_Chain_fin_230424.pdf; and https://link.springer.com/article/10.1007/s10163-024-02060-z

Wastewater sector	Inefficiency in wastewater treatment	Wastewater management bodies
Solid waste management	Leakages during collection, transportation and handling	Waste management stakeholders
Recovery sector	Leakages during recycling and Waste-to-energy processes	Recycling and waste-to-energy industry

Table 1 summarizes the source categories initially identified and key categorization aspects. A further detailing of these source categories is provided in chapter two, followed by a categorization of specific activities or phenomena where plastic leakage is most likely to occur within each category.

1.5 Avoiding double counting

A usual concern of experts dealing with the quantification and monitoring of different types of pollutant emissions is the chance of either not counting the specific substance or incurring double counting. An example of the latter, in the context of our methodology, is a piece of plastic which is initially linked to plastic production being accounted again under the waste management category.

To overcome this, our first task is to try to identify all potential points of plastic pollution (PPPP)[20] along the lifecycle of plastics, leaving no room (as far as possible) for plastic pollution not being accounted for, and yet avoiding any chance of double or fuzzy accounting. This is further developed in chapter two, where we elaborate a contextual list of PPPPs for each sector of the plastics value chain.

These pollution points are then analyzed against the conceptual framework, allowing the identification of potential overlapping or duplication in plastic flows. Material Flow Analysis (MFA) can play a crucial role on this, helping to understand how plastic waste travels from land-based sources to marine environments[21].

As an example, the explanation of why agriculture and fisheries are accounted for separately in our model may help to better understand this premise. These sectors often operate out of the spatial range usually covered by waste management systems, thus plastics leakages in these industries tend to run directly into the environment, with marginal chances of being collected or undergoing any (sound) waste management technique.

In contrast, other sectors—packaging, medical appliances, retail, etc.—are typically covered by wastewater and waste management systems, as per their location and nature of activities. Therefore, it is plausible to assume that essentially all plastic leaking from these sectors will be recovered and destined to wastewater and waste management systems; and will then be counted as plastic pollution, in case they escape the system (Figure 4 can help to better understand this approach).

[20] This is the best term we found to characterize the plastic pollution points, i.e., mechanisms and phenomena through which plastic leaks from the managed to unmanaged system. These nominations may be modified after iterations amid the review processes.
[21] Plastic Waste Material Flow Analysis for Thailand World Bank Document

1.6 Dynamics of plastics in the environment

The study of dynamics of plastics in nature is found to be a highly debated topic, with much still to be learned. While there is an overall agreement that plastic materials tend to be transported towards aquatic environments, the volume of materials being carried out and the contribution to plastic pollution of one environmental compartment to another (rivers to ocean, e.g.) is yet to be better understood[22]. Studies in the last decade identified rivers as the main conduits of plastic pollution into coastal and marine environments[23]; yet recent research suggests that rivers' contribution to plastic contamination in oceans might differ from previously thought.[24]

It is widely recognized that plastics are now ubiquitous, and can be found in aquatic, atmospheric, and terrestrial systems, and a wide variety of dynamic processes are expected to influence the distribution, transport and fate of plastic across such compartments. While scientific research on plastic pollution has historically focused on marine and riverine environments, terrestrial and atmospheric plastic contamination has started to gain more attention in recent years only.[25]

The movement, transport, and retention of plastic particles in riverine systems are influenced by hydrological processes and the features of river catchments, including land use, vegetation, and the physical structure of the rivers. In parallel, plastic transport through rivers can be directly associated with the fluctuations in the river discharge, and while flood events may enhance the mobilization of plastics, their effects tend to be more localized[26] -yet with more significant impacts, up to ten times greater on some occasions.[27]

These results suggest that there is considerable annual fluctuation in plastic mobilization, a factor that has frequently been neglected by global transport models[28]. And while it is widely recognizable that the dynamics of plastics in riverine systems are affected by seasonal and locational variations -by factors such as river flow, presence of floating vegetation that retains plastic and weather conditions, like wind and rainfall-, the current knowledge on this is still limited in scope, and more studies are needed to better understand how hydrology, wind and other factors can affect the transport of plastics in nature[29].

In addition, the characteristics of plastic materials and particles also play a role in determining the fate of plastics in aquatic environments.[30] Hence, analytical outlooks need to incorporate as much as possible the physical aspects, such as size, shape, and

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22 https://doi.org/10.1016/j.watres.2023.120329
23 Some of the most recent research has been developed by Jambeck et al. 2015, Lebreton et al. 2017, Schmidt et al. 2017, Cordova and Nurhati 2019, Nihei et al. 2020.
24 https://www.annualreviews.org/content/journals/10.1146/annurev-environ-112522-072642
25 https://www.sciencedirect.com/science/article/abs/pii/B9780128178805000074; https://www.sciencedirect.com/science/article/pii/S0304389424018788; https://link.springer.com/article/10.1007/s00128-020-02820-1
26 https://doi.org/10.1038/s44221-023-00092-7
27 https://doi.org/10.1088/1748-9326/abd5df
28 For the purpose of this paragraph, we refer to global transport models for plastics, which are tools used to estimate how plastic debris moves through various environments, particularly in freshwater and marine systems.
29 https://doi.org/10.1038/s44221-023-00092-7
30 https://www.sciencedirect.com/science/article/abs/pii/S0048969724067755?via%3Dihub

density (buoyancy), as well as the chemical properties, like composition and biodegradation, concerned to the materials/system under analysis.

As initially outlined, recent studies suggest that rivers serve not only as pathways but also as storage sites for plastic pollution, and the transport and accumulation of plastic waste along riverbanks is expected to decrease significantly as we move downstream, leading to the idea that rivers also act as reservoirs for plastic waste[31,32]. Meanwhile, studies now suggest that the number of rivers contributing to the bulk of global plastic pollution is one to two orders of magnitude higher than initial estimates, following a wider availability of more and better, more granular data, which allows for adjustments in the analytical models to better incorporate different conditions and components around riverine plastic pollution and its dynamics.[33] As mentioned, rivers play a key role in transporting plastic litter to the sea, though some may be trapped on banks, breaking down into microplastics. Factors like catchment features and human activities influence this process. The need to understand macro- and microlitter fluxes is still a relevant challenge.

When it comes to terrestrial and atmospheric systems, despite a need for more investigations for clearer conclusions, it is safe to say that plastics can accumulate on land[34] or even be transported from water to land or to atmosphere,[35] whereas atmospheric suspension and fallout and airborne transportation of plastics across the atmosphere are dictated by phenomena like precipitation and wind.[36]

While it may seem unfeasible to get a comprehensive understanding of the dynamics of plastic pollution across the environment, the information gathered here is solid evidence of the efforts of the scientific community in trying to better understand the fate of plastics once they are out of the managed system; and serves as a foundation to connect these findings with other realms of the political and scientific spheres.

1.7 The Role of Environmental Monitoring

Environmental monitoring may be a useful tool to better understand the plastic dynamics on the environment and especially (in the present context) the plastic concentration and their trends, across different systems. It is also a good instrument to connect pollution points back to pollution sources, in a bottom-up approach, allowing the correlation of locus of plastic pollution with the type of litter found, combining environmental, spatial and socioeconomic data. Environmental monitoring can likewise provide other kinds of analyses such as temporal and spatial trends, environmental target achievement levels or the effectiveness of interventions;[37] all extremely useful for the validation of plastic

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[31] https://doi.org/10.1038/s44221-023-00092-7

[32] For example, a recent study on the Mekong River in Cambodia showed that near-surface transport dominated plastic loads in the river cross-sections, especially in terms of mass; yet, mixing was observed well down the water column for all three distributaries, suggesting that significant plastic quantities may be retained in the riverbed as well. https://doi.org/10.1088/1748-9326/ac2198

[33] 10.1126/sciadv.aaz5803

[34] https://www.annualreviews.org/content/journals/10.1146/annurev-environ-112522-072642#right-ref-B44

[35] https://doi.org/10.1146/annurev-environ-112522-072642

[36] https://www.sciencedirect.com/science/article/pii/S0160412019330351

[37] https://publications.jrc.ec.europa.eu/repository/handle/JRC83985

pollution models' outputs or the design of environmental monitoring programs in connection with pollution patterns.[38]

As said, this can be rendered by the combination of information from the plastics value chain, either material flows or socioeconomic and spatial information, in combination with waste models with information on environmental pollution. These inputs (flows and concentrations of plastic pollution) in terrestrial, atmospheric and aquatic environments are influenced by multiple variables, (e.g. climatic and of the hydrology or geography of each system), and their inferences allow the identification and quantification of critical points of pollution (sources, sectors, locations...), ensured that accurate information is fed into the model.[39]

As a practical example, environmental monitoring can be used to assess the potential relationship between socio-economic aspects vis-à-vis plastic pollution observation in surrounding areas. One may expect such analyses to be unanimous in detecting a positive correlation between both variables, yet investigations can also go in other direction, showing no significant correlation between plastic pollution and increasing patterns of plastic production.[40] Scenarios such as this illustrate cases where more information/knowledge might be required, to render coherent variables (concentration or flux proxies, e.g.) that can satisfactorily explain the correlation between plastic value chain activities and plastic pollution.

Environmental monitoring of plastic pollution can be considered a relatively new field, with methods still being developed.[41] As methodologies and approaches are enhanced, and different studies start to converge towards a common knowledge base (through initiatives such as UNEP's GPML, IMO's GESAMP and the EU Marine Strategy Framework Directive (MSFD), we may get more and better information to address unsolved, unclear scenarios, as depicted above; entailing a better scenario to answer policy questions and facilitate decision-making.

[38] https://doi.org/10.5670/oceanog.2023.s1.17
[39] https://publications.jrc.ec.europa.eu/repository/handle/JRC83985
[40] https://www.sciencedirect.com/science/article/pii/S0048969717328024
[41] https://www.researchgate.net/publication/376456717_Guidance_on_the_Monitoring_of_Marine_Litter_in_European_Seas

Box 1 Assessment of marine plastic pollution in Europe: Aim, methodologies, and key Findings

The **From source to sea — The untold story of marine litter — European Environment Agency** aims to provide a comprehensive and holistic assessment of the drivers, sources, pathways, and impacts of marine litter, particularly focusing on plastic pollution. It adopts a "source-to-sea" framework, recognising the interconnection between plastic production, waste generation, riverine transport, and marine accumulation. The assessment seeks to inform policy makers effectively by providing a comprehensive picture for the plastic pollution in Europe. The assessment employs a **Drivers-Pressures-State-Impact-Responses (DPSIR)** framework to analyse the plastic pollution and marine litter problem in the Europe, with a pragmatical approach – taking into account the data availability.

Drivers of plastic pollution: Key methodologies for the drivers of plastic pollution include plastic demand and waste growth, showing a continuous increase, especially for plastic packaging. Data indicate that plastic production from virgin sources and plastic packaging waste has steadily risen, increasing the challenge of Europe's waste management.

Sources of Plastic Pollution: Marine litter primarily originates from mismanaged plastic waste, particularly packaging materials and small consumer plastics. The assessment identifies key waste management failures that contribute to plastic leakage into the environment: Material Flow Analysis (MFA): Used to track plastic production, consumption, and disposal, focusing on plastic packaging and small non-packaging items (PPSI), which dominate marine litter. This helps quantify the pressure exerted by plastic consumption on the environment. Increase in Mismanaged PPSI Waste: The share of mismanaged PPSI waste increased by 3.8% from 2012 to 2018, reaching 3.01 million tonnes.

Pathways: Riverine Litter Assessment Methodologies: Rivers act as critical pathways for transporting land-based plastic waste into marine environments. The study synthesises findings from riverine litter modelling. Studies estimate that 626 million floating plastic items enter Europe's seas annually, with 90% flowing into the Mediterranean and the Black Seas.

The Marine Litter Assessment Tool (MALT) is a prototype multi-metric tool designed to evaluate the status of marine litter pollution across European seas. It integrates available marine litter indicators and threshold values to provide a pollution scoring for the sea and coastal grids. Key indicators that were available in the European scale included: Beach litter: Measured as the number of litter items per 100 meters, providing insight into land-based inputs. Seafloor litter: Expressed as items per km^2, reflecting long-term accumulation in marine environments. Floating microlitter: Evaluated per cubic meter of seawater, highlighting plastic fragmentation processes and secondary pollution sources.

MALT integrates available marine litter indicators into an Ecological Quality Ratio (EQR) scale to classify pollution levels from "high" to "bad". 75% of the assessed area was defined as polluted according to the MALT assessment.

Linkages Between Drivers, Sources, Pathways, and Marine Pollution: The assessment underscores the critical need for waste prevention, improved waste management policies, and enhanced monitoring frameworks to disrupt the continuum of plastic pollution from source to sea. It highlights the increasing burden of plastic production and consumption, packaging waste, the persistent challenge of riverine plastic transport, and the urgent necessity of standardised assessment tools like MALT. It provides a holistic methodology that can be utilised to strengthen policy recommendations and technical strategies.

Developed by Mustafa Aydin

1.8 Data aspects

Plastic pollution modelling requires comprehensive and accurate data across multiple domains to produce precise and reliable results. Nonetheless, the current state of datasets in this regard is yet limited (either in quantity and quality) and lacks standardization,[42] leading to the necessity of considering alternative approaches in case the desired statistical information is not available.[43] Even so, some parameters need to be established to ensure a minimum of coherence to the model and, thus, a minimum of reliability on the product it will generate.

Data requirement

The main criteria for datasets to be considered in the proposed model are robustness, reliability and interoperability.

Robustness means that the source generating the data needs to have a solid foundation for the results. Firstly, it must be backed by a reasonable volume of samples or data points, and with an equally reasonable data frequency or repetition if applicable, to avoid skews and distorted extrapolations. The use of selective periods within a dataset or the simple extrapolation of local cases to global assumptions exemplify some of the main issues leading to lack of robustness. Secondly, calibrated parameters, initial assumptions and established indicators need to comply with scientific methods,[44] so the analytical frameworks can demonstrate to concur with observations.

In turn, data may be considered reliable if the material comes from a verified source, either scientific paper, research institutions or other sorts of organisations. The existence of review processes (peer-review, reviewer board, approval group, etc.) during the production of the materials is a further element to assess levels of reliability. In this sense, as will be detailed later, data from National Statics offices and national governments is a relevant source of information to be considered.

Finally, interoperability refers to the ability of data to be translated into new contexts, either in a different model or with alternative assumptions. For data to be interoperable, they need to be in no conflict with widely accepted conceptual frameworks dealing with the same subject. Likewise, statistics need to be granular enough and have comprehensive information about its production (date and conditions of data collection, caveats, explanation about conversion or extrapolation exercises, etc.), in order to enable researchers to take the adequate steps for data treatment and due adaptation. This is important because it allows the integration between different models of plastic pollution, enabling data exchange and reinforcement exercises between different models in a meaningful way.[45]

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[42] https://www.unep.org/resources/pollution-solution-global-assessment-marine-litter-and-plastic-pollution
[43] https://www.iges.or.jp/en/publication_documents/pub/policyreport/en/12696/Plastics_Value_Chain_fin_230424.pdf
[44] https://doi.org/10.1007/978-3-030-78627-4_6
[45] https://www.edps.europa.eu/data-protection/our-work/subjects/interoperability_en

Data sources

Three channels will be considered as main sources for data collection for the toolkit, in this order of relevance: (a) government statistics, (b) similar methodologies, and (c) academic papers and case studies; all proven to respect the abovementioned requirements.

As per government data, we anticipate some countries will present better and more granular data on plastic production, use and disposal and waste management; whereas others may present a very limited number of such datasets -especially when it comes to disposal and waste management-.[46] As this toolkit is mainly aimed at developing economies and these are most likely to be among the countries with less and poorer data, this must be a point of attention as the toolkit development advances.

Furthermore, the main existing methodologies and platforms dealing with plastic pollution modelling will likewise be a primary source of information and inputs for the toolkit, having as a starting point the baseline study[47] previously developed under this same project.

In case reliable, robust and interoperable data is not found in the two above options, case studies and scientific papers may be used for the establishment of proxies in support of the development of leakage factors.

Data validation

Consonant with the explained above, a formal revision of datasets subject to be used will be carried out, in line with widely established concepts and definitions within environmental and pollution statistics frameworks.[48]

Techniques such as cross-check between analogous studies and validation checks contrasting independent and dependent variables (cause and effect) may be used on this regard, in addition to a continuous vigilance on eventual outliers and anomalies in the data being handled.

As a result, performance or quality categorisation may be carried out, and if relevant, data categories may be established based on the quality or characteristics of datasets.[49] This will contribute to ensure the best use as possible of available information, promoting consistency between related variables and coherence of input data with the proposed model.

[46] https://www.unep.org/resources/global-waste-management-outlook-2024
[47] https://wedocs.unep.org/20.500.11822/46118
[48]https://unece.org/statistics/publications/conference-european-statisticians-framework-waste-statistics
[49] https://www.sciencedirect.com/science/article/pii/S1364815212002435

1.9 Units of measurement

Estimates of fluxes of plastic pollution are usually expressed in literal quantities (numbers of particles or total weight in grams or kilos) or mass-based weight (grams or kilos of mass-based weight), and these may be eventually accompanied by a ratio variable (per litre, per cubic meter, per second/minute), depending on the nature of the phenomenon or analysis.[50] More specially, for macrolitter weight measurements, it could be applied, but together with common units, e.g :litter items/100 m on beaches, litter items/km² on the seafloor, or on the sea surface, or on land, items/hour in rivers, etc.

While both number of particles and weight may be relevant for data collection analyses and environmental monitoring purposes, the proposed toolkit will prioritise mass-based units of measurements, as it is assumed to make more sense from a policy perspective.

The reasons to prioritise units of measurements based on the weight of plastics include a precautionary approach and a better consistency in reporting, as mass measurements provide a more consistent basis for comparison across different models and plastic pollution sources, better alignment with economic metrics used in many of the sectors, and practical implications for policy intervention.[51] By doing this, we assume that a reliable information about the estimated total mass of plastic leakage might be more relevant for decision-making than estimations on metric volume or number or format of plastic particles in the environment.[52]

We recognize though that this is a limited view of a more complex situation, and such granularity will certainly be necessary for other analytical endeavours, such as validation analyses and environmental monitoring.[53]

Therefore, the toolkit intends to follow some of the major standard guidelines and monitoring programmes on plastic and plastic pollution across the world. Thus, we intend to follow UNEP-UNITAR's "Statistical guideline on measuring flows of plastics along the life cycle"[54] and UNECE's "Conference of European Statisticians Framework on Waste Statistics", in addition to standards adopted for waste-related SDG indicators[55], which prioritise the use of kilos or tonnes to indicate plastic mass volumes, preferentially on yearly bases.

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[50] http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean
[51] https://unece.org/statistics/publications/conference-european-statisticians-framework-waste-statistics
[52] https://council.science/wp-content/uploads/2023/11/ISC_policy_brief_plastics_WEB.pdf
[53] http://www.hbm4eu.eu/wp-content/uploads/2019/03/2019_RI_Report_A-circular-economy-for-plastics.pdf
[54] https://unece.org/sites/default/files/2024-03/S2b_1_On%20plastics_Ekaterina%20Poleshchuk_UNEP.pdf
[55] UNEP-UNSD-UNITAR custodianship for Reporting on waste-related SDG indicators.

1.10 Target audience

This toolkit is primarily aimed at UN Member States struggling with limited capacity to identify sources of plastic pollution and quantify the amount which will eventually enter the aquatic environment, in order to derive efficient targeted measures. Under this context, the direct users may be government officials working in national statistical offices, particularly on divisions working more closely with environment- or pollution-related statistics.

The information generated may then be used by decision-makers to design policy interventions or develop national action plans addressing plastic pollution, whereas civil society –river basin committees, regional fisheries bodies, environmental NGOs, citizens, and others– may also use the toolkit outputs in aspects concerning to plastic pollution within their activities, or yet to advocate for action against plastic pollution at sub-national or national level.

At international level, the toolkit may also be relevant for the design of strategies and action plans, for entities such transboundary river and lake basin organizations or Regional Seas Conventions;[56] not to mention its potential to be used for monitoring or accounting purposes under global agreements, such as the legally binding instrument on plastic pollution being currently discussed by Member States.

Additionally, this toolkit may also be of interest to academy practitioners, scientists and other individuals and entities dealing with, studying, or just interested in learning more about plastic pollution.

1.11 Other principles and aspects concerning to the toolkit

Life Cycle Approach

Our methodology stands for the consideration of the whole life cycle of plastics as the only effective way to curb plastic pollution[57]. Hence the definition of source categories that go from the production to the end-of-life of plastics is a central element of the toolkit.

Effectiveness in the toolkit development

For the full development of an initial toolkit in a short timeframe, it may be unavoidable to resort to simplification and prioritization efforts to get to the end of the project with a consolidated methodological proposal. We are cognizant yet that by being pragmatic and avoiding complexity we may forego some important aspects that are likely to be as relevant as the topics covered under the toolkit -these topics may be addressed at a later stage, as part of reinforcement processes or additional features to the toolkit.

In the same vein, some elements or sectors which present more and better data or that are expected to have more impact against the project's objective may be prioritised, as per their relevance and additionality considering an initial toolkit proposition.

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[56] https://www.unep.org/topics/ocean-seas-and-coasts/regional-seas-programme
[57] https://www.unep.org/news-and-stories/story/how-can-life-cycle-approach-curb-plastic-pollution-crisis

Action-oriented

The toolkit is envisaged to provide actionable outputs, representing a direct source of information for policymaking. Thus, we will prioritise coherence over granularity of information, so that the generated results can be easily understood by decision-makers and society, and at the same time make sense with the real world and the current scenario of plastic pollution and required actions. This goes in line with the simplification approach mentioned above.

Practical

Our diagnosis shows that existing plastic pollution mapping models can hardly be used by government officials without relying too much on physical models and complex algorithms, and that they can assess plastic pollution sources in a comprehensive manner. This toolkit will try to address this problem by being as simple as possible, trying to avoid deeply technical analytical elements and keeping the analyses as comprehensive as possible, but without losing sight of coherence involving the collected information and results generated.

Also, as the priority audience are developing economies struggling to have better information about plastic life cycle and plastic pollution, this toolkit is intended to remain open-source and to be operable in widely used systems and software.

Scalable

As said, pragmatism may be adopted as part of an initial strategy to come up with a consolidated proposal for a toolkit to map plastic pollution from a plastic value chain perspective. Notwithstanding, the methodology will be developed taking into account the possibility/necessity of being scaled-up or adapted to different, larger contexts; including the inclusion of additional features or the consideration of new sectors, or even the incorporation of environmental monitoring aspects. This also entails the toolkit is intended to be dynamic, allowing its adaptation to different regional and operational approaches, such as city-level or river basin-level analyses.

Harmonization

One of the requirements for data to be considered in the toolkit is that they need to be interoperable (Section 1.10). Logically, the toolkit aims to likewise harmonize with existing methodologies and widely accepted analytical frameworks. The formation of a multi-skilled Working Group and the production of a baseline study on major existing plastic waste estimation models[58] go in this direction.

[58] https://wedocs.unep.org/20.500.11822/46119

1.12 What this toolkit is not intended to cover

Due to time-bounded and technical constraints, this toolkit will initially focus on the estimation of overall plastic leakage along the plastic value chain. Therefore, chemical, biological and physical parameters (macro-, micro-, nano; fragment, fiber, nurdle, etc.) are not expected to be considered in the model's outputs, nor will different plastic waste streams (plastic types, hardness, colour), plastic application (textile, packaging), plastic types (PP, PET…) and chronological aspects (plastic lifetime).

In the same vein, impacts of plastic pollution on humans and societies are beyond the model, as the toolkit will not touch on topics like toxicity, sociology, climate change, biodiversity, etc. Moreover, the toolkit intends to simply identify points where plastics are leaking, not necessarily entailing any implication to the responsible(s) or the responsibility for such phenomenon (e.g. WWTPs receive and treat plastic waste that is generated by other sectors up in the value chain).

All these factors might be useful as per the development of leakage factors, yet they are not expected to be distinguished among the toolkit outputs -unless necessary or convenient. Notwithstanding, these elements may represent foundational information allowing the extrapolation of the model's findings into other fields in the future, for a better understanding of plastic pollution against these peripherical aspects.

2. Source categories

The categories introduced in the conceptual framework are further detailed here, with an initial context discussing the dynamics of plastics in each category, with their main assumptions, key aspects and major actors, in addition to potential sources of information.

This is followed by a categorization of identified “potential plastic pollution points”, referring to potential phenomena or activities that lead to plastic leakages into nature. This section is supposed to be just a description of the exact moment (activity, phenomenon) at which leakage may occur, regardless of drivers and/or ex-ante or ex-post material pathways.

This is aimed at being the central element for the development of leakage factors in a later stage and is complemented by an indication of potential methodologies and studies deemed as good candidates to provide information for the development of leakage factors.

2.1 Plastic production

Context

The production of plastic is a multi-step process that transforms raw materials, primarily derived from fossil fuels, into a wide variety of plastic products, through a process that can involve several stages, including raw materials extraction, raw material conversion (into monomers) and plastic production (monomers are linked together to form polymers).[59]

The starting point is the processing of primary raw material into intermediates needed subsequently in the chemical reactions to obtain monomers.[60] The next stage is the production of polymers, under two major families: thermoplastics (can be softened with heat and hardened again with cold) and thermosets (softening not possible once is moulded); and these are converted into three different classes of materials, according to market specifications (demand): plastics in primary forms, semi-finished plastic products, and plastics in finished products, which includes finished plastics products and plastics embedded in plastics containing products.[61]

As depicted in Figure 5, petrochemical companies and plastic converters, compounders and manufacturers are the major actors in this source category. Industry and trade statistics linked to these sectors might be a good source of information for the identification and quantification of plastic leakage.

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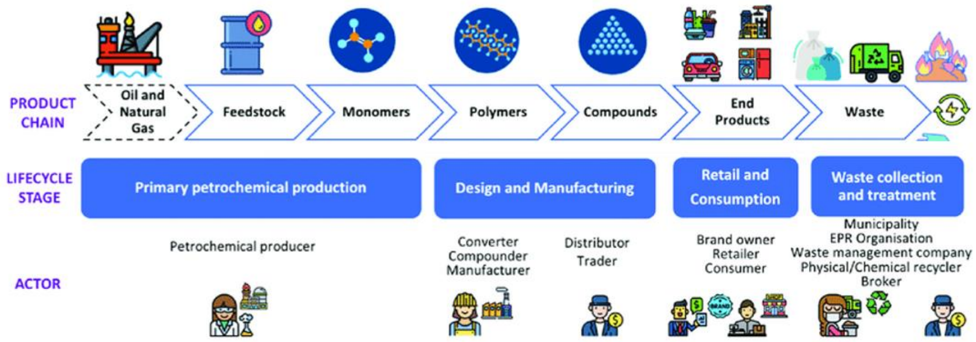
[59] https://doi.org/10.1080/21655979.2021.1902173;
[60] https://doi.org/10.12911/22998993/151815
[61] https://unece.org/sites/default/files/2024-03/S2b_1_On%20plastics_Ekaterina%20Poleshchuk_UNEP.pdf

Figure 5 - The plastic value chain, showing the actors, life-cycle stages, and key routes for secondary materials.



Extracted from: 10.1016/j.spc.2022.08.019

Potential plastic pollution points

Monomer production (chemical reactions, industrial processes): losses during the processing of raw material into intermediates for the required chemical reactions that will result in monomers[62].

Plastic production (Other potential name could be "Manufacture of plastics and synthetic rubber in primary forms"): losses during polymerization and polycondensation reactions (majorly) to form a new substance (polymers). Both reactions require specific catalysts and are usually done through several thermal reactions[63]. Polymerization is the most frequent process, used to obtain 75% of synthetic polymers manufactured worldwide.[64]

Table 2 Release pathways: Activities potentially related to plastic emissions during the plastic production process

Activity/phenomenon	Potential references
Spillage of melted materials during conversion processes (melting, extrusion)	
Spillage during waste handling within the facility	
Littering of excess material trimmed after molding	
Disposal of waste from finished products or materials	
Disposal of failed or trial batches	
Microplastics through air dispersion (fumes, heating processes, dispersed dust)	
Microplastics in wastewater and in colling systems	
Littering of support materials (machinery, office supplies illegally discarded)	

[62] https://doi.org/10.12911/22998993/151815
[63] https://www.sciencedirect.com/science/article/pii/S0014305700000537; https://plasticseurope.org/plastics-explained/how-plastics-are-made/.
[64] https://melscience.com/JP-en/articles/polymerization-and-polycondensation-reactions/?srsltid=AfmBOophsoVQ7YFfn-Lu55PQHu0ptlvp2CexFvQ3d4Z6oc1VeMxwVvwK

Related methodologies

Basel Convention Practical guidance for the development of inventories of plastic waste

UNEP/UNITAR's Statistical guideline on measuring flows of plastic along the lifecycle

Breaking the Plastic Wave Pathways Tool, Pew Charitable

National Guidance for Plastic Pollution Hotspotting and Shaping Action, (UNEP- IUCN)

OECD ENV-Linkages Model

Plastic Leak Project

UN Environment (2018). Mapping of global plastics value chain and plastics losses to the environment (with a particular focus on marine environment)

2.2 Production of plastic products and plastic-containing products

Context

Plastic polymers in primary form are used as inputs to manufacture a host of products, some of which are finished products, others are inputs into the production of other goods (e.g., plastic components for electric vehicles, building materials and medical equipment).[65] Companies manufacturing plastic goods use feedstocks of plastic materials which are melted and formed into plastic products. The feedstock typically consists of small pellets, although flake and powder forms are sometimes used -yet, literature and data often do not distinguish between these forms of raw material.[66] Plastic products are then assembled or mixed with other materials to manufacture finished goods for final consumption (households, businesses).

Blow molding is a predominant method in the plastics manufacturing industry, where an extruded plastic tube inflates to take the shape of a predefined mold. This technique primarily utilizes thermoplastics, with high-density polyethylene (HDPE) being the preferred choice.[67]

There are three main types of blow molding: injection blow molding, extrusion blow molding, and stretch blow molding. Injection blow molding combines traditional injection and blow molding principles, starting with molten plastic injected onto a metal rod within a mold to create a preform. This pre-form then enters another mold, where compressed air shapes it into the final product, offering high precision, especially around the neck of containers. Extrusion blow molding involves extruding a hollow preform, sealing one end, and then using compressed air to inflate it into the mold. This method can be continuous or intermittent and is typically used for products like water bottles

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[65] https://www.oxfordeconomics.com/wp-content/uploads/2024/04/2024-ICCA-Oxford-Economics-report.pdf
[66] The Plastic Leak Project Guidelines - Quantis, pp. 148
[67] Blow Molding Technology Overview

and automotive components. Stretch blow molding adds an extra step by stretching the pre-form before inflation, enhancing mechanical strength.[68]

Other plastic fabrication methods include extrusion, which creates long continuous pieces with consistent cross-sections like tubing and pipes; rotational molding, used for large hollow parts such as tanks by heating and rotating molds; and thermoforming, which involves heating plastic sheets until pliable and forming them over molds to create shallow parts like packaging trays. Together, these methods highlight the versatility and efficiency of plastic manufacturing processes in producing a wide range of products.[69]

Potential plastic pollution points

Both in the stage of plastic products production and the production of plastic-containing products there is a general assumption that there may be "unintentional spills during production"[70] related to:

- Losses of plastic pellets during products or packaging manufacturing.[71]
- Spills occur during handling, loading, in-process transport, and unloading, as well as leakage from containers and storage silos, during activities of melting and remolding of plastic pellets (usually compounds) carried out by processors or converters.[72]
- Littering or burning of excess materials (particularly in the form of flash or trimmings) from blow molding during the process of crafting hollow plastic items.[73]

Related methodologies

Plastic Leakage Project

UNEP/UNITAR's Statistical guideline on measuring flows of plastic along the lifecycle

OECD ENV-Linkages Model

[68] Blow Molding Technology Overview
[69] Plastics Manufacturing: Types of Plastic and Processes
[70] https://doi.org/10.2305/IUCN.CH.2019.10.en
[71] The Plastic Leak Project Guidelines - Quantis
[72] The Plastic Leak Project Guidelines - Quantis
[73] Blow Molding Technology Overview

2.3 Plastic Use in Selected Sectors/Activities

This section introduces plastic uses in fisheries (including aquaculture, recreational fishing and maritime activities), agriculture, construction and mining. The rationale for the sectors presented here regards their own characteristic of direct sources of plastic pollution into the environment, whereas other sectors / economy activities (electronics, toys, packaging, medical appliances, etc.) are assumed to be mediated by some type of waste or wastewater management stage (more explanation on this can be found on Section 1.5).

Fisheries, aquaculture and maritime activities

Context

This source category refers to plastic pollution arising from the fisheries (professional and recreational) and aquaculture sectors, as well as maritime activities. The magnitude of losses remains uncertain but studies suggest that fishing and aquaculture could be responsible for approximately 640,000 tonnes of plastic pollution per year, representing around 10% of all plastic debris in the ocean.[74] As per losses from marine activities, there is a limited amount of information available but float and buoys are often found amid plastic marine debris,[75] suggesting the relevance of the sector as a contributor to global plastic pollution.

Recent studies highlight complexities in estimating global abandoned, lost or otherwise discarded fishing gear (ALDFG), identifying data gaps and raising questions and recommendations about some of the oft-cited estimates [76]. Richardson *et al.* (2022) interviewed fishers around the world about their fishing gear losses, and compared that to reported losses by global fishing effort data. They estimated that nearly 2% of all fishing gear (comprising 2963 km^2 of gillnets, 75,049 km^2 of purse seine nets, 218 km^2 of trawl nets, 739,583 km of longline mainlines, and more than 25 million pots and traps) are lost to the ocean annually.[77] Plastic waste from fishing gear disposed of on land may also contribute to plastic pollution, but data is quite limited in this regard.[78]

The past few decades have seen the fishing industry increasingly rely on plastic in the form of nets, lines, ropes, traps and other fishing equipment. These materials are often lost by accident, as rough weather conditions and worn gear cause the equipment to break while in use; or in illegal and unregulated fisheries, when fishing vessels deliberately release their equipment into the environment. Figure 8 illustrates these and some other aspects contributing to marine plastic pollution, even though once these plastic materials break down to microplastics, it is increasingly difficult to identify the source of the plastic waste.[79]

Figure 7 - Fisheries and aquaculture practices contributing to marine litter and plastic pollution

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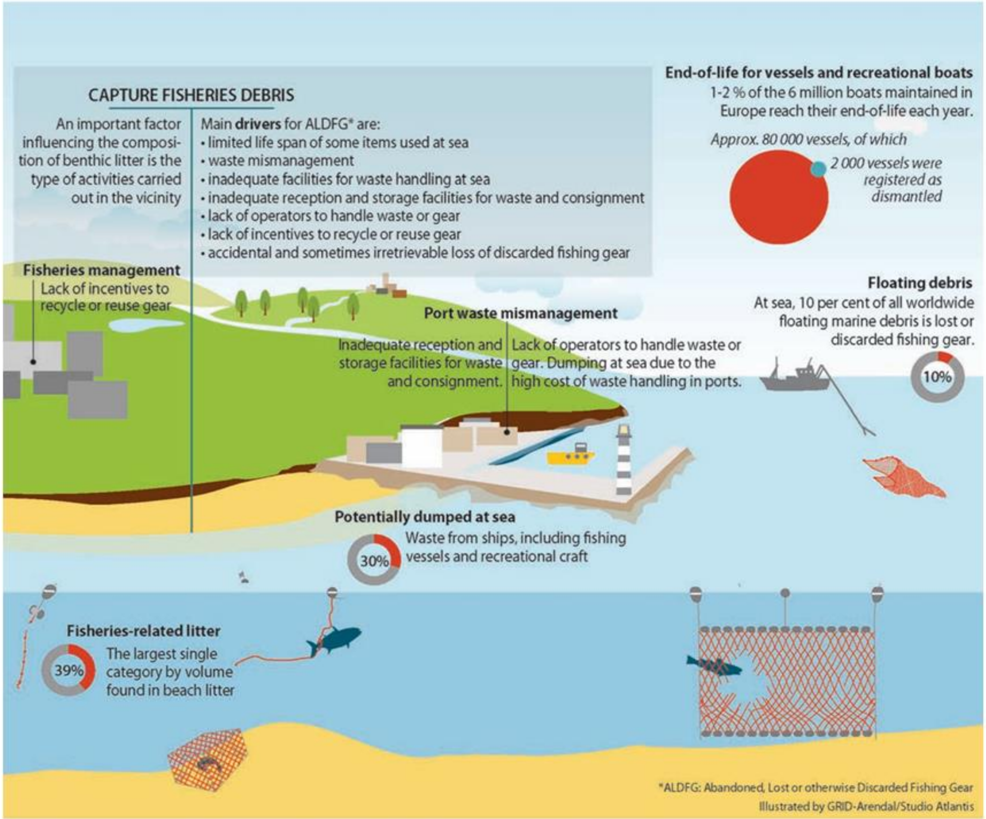
74 https://doi.org/10.1016/j.marpol.2021.104846
75 UN Environment (2018). Mapping of global plastics value chain and plastics losses to the environment (with a particular focus on marine environment)
76 Assessment of agricultural plastics and their sustainability: A call for action
77 https://doi.org/10.1126/sciadv.abq0135
78 Assessment of agricultural plastics and their sustainability: A call for action
79 https://doi.org/10.1016/j.marpol.2021.104846



Source: UNEP 2021

Potential plastic pollution points

ALDFG may represent the main source of pollution in fishery, aquaculture and recreational fishing, referring to plastic materials and equipment lost to the environment, either intentionally (littering) or accidentally.

When it comes to marine activities, plastic pollution could come from losses of materials like nets and cage structures for marine fish cages), lines and floating raft structures (for seaweed systems), and poles, bags, lines and plastic sheeting (for mollusk farming). The fragmentation and degradation of materials exposed to marine/coastal conditions represents another source of plastic pollution,[80] in addition to abandoned end-of-life vessels and boats -especially those made of fiberglass-.[81] The natural deterioration of vessels and dismantling activities (shipbreaking) are also PPPPs, from the breakdown of plastics into small or micro-particles, or also in the form of plastic-containing paints, waxes and oil leaking from the vessels and equipment to the ocean.

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[80] https://www.sciencedirect.com/science/article/pii/S0025326X17302035?via%3Dihub
[81] https://www.unep.org/resources/pollution-solution-global-assessment-marine-litter-and-plastic-pollution

Related methodologies

FAO - [ASSESSMENT OF AGRICULTURAL PLASTICS AND THEIR SUSTAINABILITY A CALL FOR ACTION] suggests a guidance for assessment of related use risk (including Potential for leakage into the environment at site of use) for a set of Agriculture Plastic products, including the categories of Fisheries and Aquaculture (Fishing nets and ropes, Net float, Cages, EPS boxes)

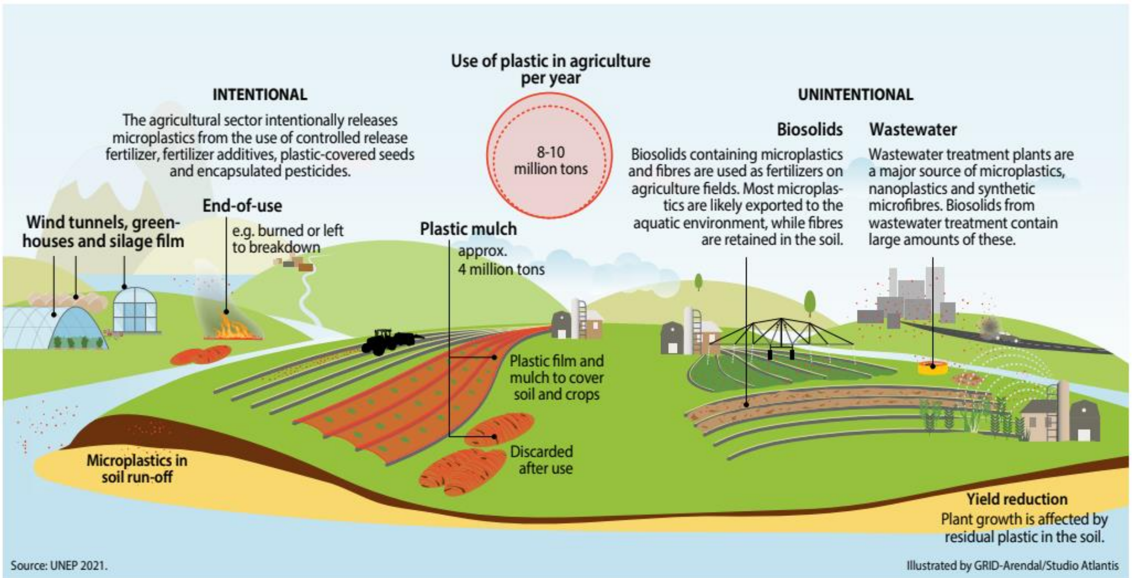
The document [UN Environment (2018). Mapping of global plastics value chain and plastics losses to the environment (with a particular focus on marine environment)] offers an average global plastic loss for a set of categories for Micro and Macroplastics.

Agriculture

Context

Plastic products are widely utilized in all facets of agriculture (Figure 8), including plant cultivation, forestry and livestock management, for feeding and animal care, and the sector comprises about 4% of plastic produced globally.[82] While the figure might not be impressive in a global outlook, the sector is registering a notable increase in the use of plastics in recent decades,[83] and waste management nowadays has become a serious topic for farms, with implications not only for human and ecosystems health but also for the effective management of soils.[84] Agricultural soils are thought to receive today greater quantities of microplastics than oceans.[85]

Figure 8 - Agricultural practices contributing to marine litter and plastic pollution



Source: UNEP 2021

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[82] https://www.mdpi.com/2071-1050/16/3/954
[83] https://www.chemistryworld.com/features/the-problem-of-plastic-in-our-soils/4020364.article
[84] https://www.sciencedirect.com/science/article/pii/S0048969721039619
[85] Assessment of agricultural plastics and their sustainability: A call for action

Plastics used by the sector can be classified into three primary categories, according to their physical characteristics: flexible products, which include mulch films, tunnel films/nets, bags, silage films, non-woven textiles, and fishing netting; semi-flexible products, such as tubes, driplines, tree guards, and ropes; and rigid products, which consist of bottles, baskets, cages, and fishing floats.[86]

Greenhouse and films generally represent the largest quantities of nonpackaging plastics used in agriculture. Another use of plastics in agriculture is related to polymer-coated fertilizers that supply nutrients to plants at controlled rates, minimizing emissions to water and air. In livestock farming, silage films enable the production of healthy, durable fodder without the need for barns or silage clamps, whereas plastic tree guards are commonly used in forestry to protect young trees.[87] Plastics are also utilized in pre and post-harvest operations, including seedlings and feed storage for livestock[88] Table 3 presents a more detailed list of practices using plastics.

Another use of plastics in agriculture is related to polymer-coated fertilizers that supply nutrients to plants at controlled rates, minimizing emissions to water and air. In livestock farming, silage films enable the production of healthy, durable fodder without the need for barns or silage clamps, whereas plastic tree guards are commonly used in forestry to protect young trees.[89] Plastics are also utilized in pre and post-harvest operations, including seedlings and feed storage for livestock[90]. Table 3 presents a more detailed list of practices using plastics.

These characteristics affect how they enter terrestrial and aquatic ecosystems and their subsequent behaviour within those environments. Once in the environment, plastic pollution can fragment into smaller pieces of plastic[91]. It is important to note that most agricultural plastics are designed for single use, although their useful lifespan can vary from 1 (mulching films) to more than 5 years (greenhouses cover, irrigation pipes) 8 years based on the application and the region where they are utilized. Most of these plastics typically become waste within a year[92], yet part of it -particularly pesticide plastic packaging- are duly channelled to waste management and recovery systems through deposit-refund schemes and alike,[93] and thus do not entail plastic pollution.

Most data sources defined agricultural plastics as those used in the production phases of value chains. Data on plastic products used in the middle and later phases of agricultural value chains were difficult to disaggregate from total packaging waste. It proved impossible to attribute quantities of such products to specific agricultural value chains. According to FAO (2021), there is no specific data available for plastics used in the agrifood value chains between production and consumption i.e. storage, processing, transportation and distribution, whereas estimations related to plastic usage in the consumption of agricultural products are easier to find.[94]

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86 Assessment of agricultural plastics and their sustainability: A call for action
87 Assessment of agricultural plastics and their sustainability: A call for action
88 Plastics in Agriculture: Sources and Impacts - Working Paper
89 Assessment of agricultural plastics and their sustainability: A call for action
90 Plastics in Agriculture: Sources and Impacts - Working Paper
91 Impacts of Plastic Pollution | US EPA
92 Assessment of agricultural plastics and their sustainability: A call for action
93 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3669548
94 Assessment of agricultural plastics and their sustainability: A call for action

Table 3 - Agricultural practices making use of plastic products

TYPE OF AGRICULTURE	ACTIVITY	EXAMPLE PRODUCTS
Plant production	Seeding	Seed containers/bags, polymer coated seeds, plant pots, seed trays
	Cultivation	Mulch film, greenhouse films, non-woven textile protection "fleece", protection nets, plant support twine and clips, pesticide containers, fertilizer containers, polymer coated fertilizer, hydroponic bags and slab wraps, supports/posts, spray tanks, personal protective equipment
	Irrigation	Drip tape, pipes, drippers, pond and canal liners
	Harvesting and transportation	Boxes, crates, pallets, insulated crates
	Ornamental plants	Pots, clips, supports, labels, trays, supports/posts, twine, plastic covered wires, soft plastic grow bags, mulch films or ground cover liners (e.g. in container nurseries), pesticide containers and personal protective equipment
	Storage	Hermetic sealed bags
Livestock	Feed and fodder production	Fertilizer containers, polymer coated fertilizer, seed containers, silage films, bale wrap, twine and net, feed sacks, personal protective equipment
	Animal care	Crates, ear tags, bottles, and containers for medicines and hygiene products, personal protective equipment
Forestry	Plantation management	Controlled release fertilizers and their containers, plant protectors, tree guards, mulch films, pesticide containers, chainsaw fuel and lubricant containers

Source: FAO (2021) Report Assessment of agricultural plastics and their sustainability: A call for action

Potential plastic pollution points

Agricultural plastics that are not collected for separate recycling or formal disposal may enter terrestrial and aquatic ecosystems through any one of three main mechanisms: through being damaged, degraded or discarded. Damaged plastics are those that sustain harm in their operational environment, often due to poor material selection, management issues, or animal interactions, leading to unintended release of plastic fragments into ecosystems. Degraded plastics result from prolonged exposure to environmental factors that weaken their structure, making them more vulnerable to disintegration and dispersion by natural elements like wind and water. Lastly, discarded plastics refer to the improper disposal of agricultural materials, including littering and burning, particularly in areas lacking environmental controls.[95]

PPPPs can be identified in either crop production, forestry and livestock management. In the first they can refer to pre- and post-harvest activities, such as controlled release fertilizers (CRF), mulching, seed coatings, plastics used to store harvested crops, and in the dispersal of wastewater biosolids or treated wastewater from wastewater treatment plants (WWTP).

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[95] Assessment of agricultural plastics and their sustainability: A call for action

In forestry, the use of labels and guards in trees may represent main PPPP, whereas in livestock management higher risks of plastic pollution come from the tagging of animals and management for feed stocking (foraging).

The open burning of agriculture plastic waste (even pure or mixed with other agriculture waste residues) may be likewise considered across all these subsectors.

Related Methodologies

FAO's ASSESSMENT OF AGRICULTURAL PLASTICS AND THEIR SUSTAINABILITY A CALL FOR ACTION suggests a guidance for assessment of related use risk (including Potential for leakage into the environment at site of use) for a set of Agriculture Plastic products.

Plastic waste index, proposed in Hachem at al.

Mining

The mining industry employs a variety of plastics for numerous applications, mainly because of their durability, chemical resistance, and lightweight characteristics. Commonly used plastics in mining operations include high-density polyethylene (HDPE), polyvinyl chloride (PVC), polycarbonate (PC), and ultra-high molecular weight polyethylene (UHMW-PE)[96]. These materials serve essential functions, including:

- **Safety Equipment**: Plastics are utilized in hard hats, safety goggles, and protective barriers to enhance worker safety.
- **Piping Systems**: High-density polyethylene (HDPE) and polyvinyl chloride (PVC) are commonly employed for waste transfer and slurry lines due to their resistance to corrosion and leakage.
- **Heavy Machinery Components**: Polycarbonate and acrylic plastics are used for glazing in heavy equipment, offering visibility while shielding operators from debris.
- **Lining Materials**: Plastics serve to protect machinery and surfaces beneath them from wear during material handling operations.

Potential plastic pollution points

During mining operations, especially in open-pit mining, plastic materials utilized for different functions (such as containment or equipment) may become dislodged and escape into the environment. This encompasses plastics from safety gear, machinery parts, and other operational materials.

Not much more information or studies were found about plastic pollution in the mining sector, therefore we assume that its contribution to plastic pollution is marginal and/or more research is needed and will eventually disregard it for the purpose of this toolkit.

[96] Plastic for Mining Applications: Popular Plastics Used in the Mining Industry — A&C Plastics

Construction

Plastic pollution in the construction and built environment is emerging as a significant concern, largely driven by the ubiquitous use of plastic-based materials. In their recent study, Prasittisopin, Ferdous, and Kamchoom (2023) explain that materials such as PVC pipes, insulation foams, synthetic coatings, and other polymer-based products are integral to modern construction. However, as these materials age or are subjected to physical and chemical weathering, they gradually break down into microplastic particles[97]. This degradation occurs throughout the entire lifecycle of construction materials—from installation and routine maintenance to demolition and disposal, construction sites themselves can be hotspots for microplastic emissions. It is important to highlight that according to Geyer et. Al. (2017) the building and construction sector, which has used 69% of all PVC, is a large consuming sector, using 19% of all non-fiber plastics[98].

It is also relevant to underline that, in the case of plastic leakages from construction, the focus of this section is on plastic materials while erosion of painted surfaces is approached under the following section.

Potential pollution points

Weathering and abrasion from environmental exposure cause surface fragmentation of painted coatings and plastic components on buildings and infrastructure. During demolition activities, large amounts of plastic waste are often generated, and if not properly recycled or contained, these materials further contribute to the ambient microplastic load in urban settings

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[97] https://doi.org/10.1016/j.dibe.2023.100188
[98] https://doi.org/10.1126/sciadv.1700782

2.4 Diffuse Pollution

This section presents a series of sources related to emissions of delocalized plastics, in particular in relation to the phenomena of Tire Abrasion, Open Burning, as well as the dynamics of plastic leakage in paints and in the phenomenon of urban dust.

Context

Diffuse plastic emissions refer to the unintended release of plastic particles into the environment through everyday activities and industrial processes. These emissions are often invisible and result from gradual wear, degradation, or atmospheric transport. The major sources of such emissions include **tire abrasion, open burning of plastics, paint degradation, and urban dust**, each of which releases microplastics or nanoplastics into air, soil, and water systems. These emissions are especially concerning because they bypass traditional waste management systems and are difficult to track. They contribute significantly to environmental pollution, affecting urban areas, waterways, and even remote ecosystems through atmospheric deposition. The scale of these emissions is still being studied, but emerging research highlights their widespread impact

Tire Abrasion

Wear and tear from tyres significantly contribute to the flow of (micro-)plastics into the environment. Tires are made from synthetic rubber containing plastic polymers. As vehicles move, they shed tiny fragments that accumulate in air, soil, and waterways. According to Kole et al. (2017) the emissions from car tyres (100%) are substantially higher than those of other sources of microplastics. These particles are carried by wind, deposited on roadsides, and eventually washed into rivers and oceans. Emissions and pathways depend on local factors like road type or sewage systems[99].

Open Burning and other phenomena

Open burning plastic waste is a significant yet often overlooked contributor to plastic pollution. This practice, which involves the uncontrolled combustion of waste in open environments, releases plastics into the unmanaged system in two primary ways: as physical debris and as airborne pollutants. According to a recent study by Cottom et al. (2024), open burning accounts for approximately 57% of global plastic waste emissions, amounting to nearly 29.9 million metric tons annually[100]. Complementary, according to Wright & Kelly (2017), in regions where waste management infrastructure is lacking, open burning is a common method of waste disposal.[101]

This category comprehends sources of plastic waste which is not captured by wastewater and waste management systems, which is more common to happen in poorer or rural and peri-urban areas. Domestic-open waste burning and direct dumping into the environment illustrate two of these activities.[105] The first is more related to airborne dispersion of plastic pollution, but it may also entail risks of soil contamination from the remaining ashes and unburned materials; while the latter can be represented

[99] https://doi.org/10.3390/ijerph14101265
[100] https://doi.org/10.1038/s41586-024-07758-6
[101] https://pubs.acs.org/doi/10.1021/acs.est.7b00423

by direct littering of large and solid plastic waste into nature, but also by direct discharges or spillages of plastic-contaminated water.

Paints and Urban Dust

Paint degradation is emerging as a significant, yet often underestimated, pathway for plastic leakage into our environment. Modern paints, which are used extensively in urban infrastructure, road markings, marine vessels, and industrial equipment, contain synthetic polymers engineered for durability and aesthetic appeal. However, over time, these polymers undergo weathering and degradation, releasing microplastic particles into the surrounding environment.

In parallel, Brahney et al., (2021) found that urban dust, a mixture of fine particulate matter, often carries microplastics from degraded plastics, construction materials, textiles, and other sources. During rainfall, these microplastics are washed into drainage systems, further polluting aquatic environments[102].

Potential Pollution points

For diffuse pollution, some of the following can be identified as potential pollution points:

- Open Burning of Plastic Waste
- Direct dumping of plastic waste into nature
- Weathering and Erosion of Painted Surfaces
- Direct emission from tyre used in transport sector
- Emissions from mechanical erosion of road marking (Paints)

Related methodologies

WASTE WISE CITIES TOOL

Plastic Leakage Project

UNEP/UNITAR’s Statistical guideline on measuring flows of plastic along the lifecycle

Basel Convention Practical guidance for the development of inventories of plastic waste

[102] https://doi.org/10.1073/pnas.2020719118

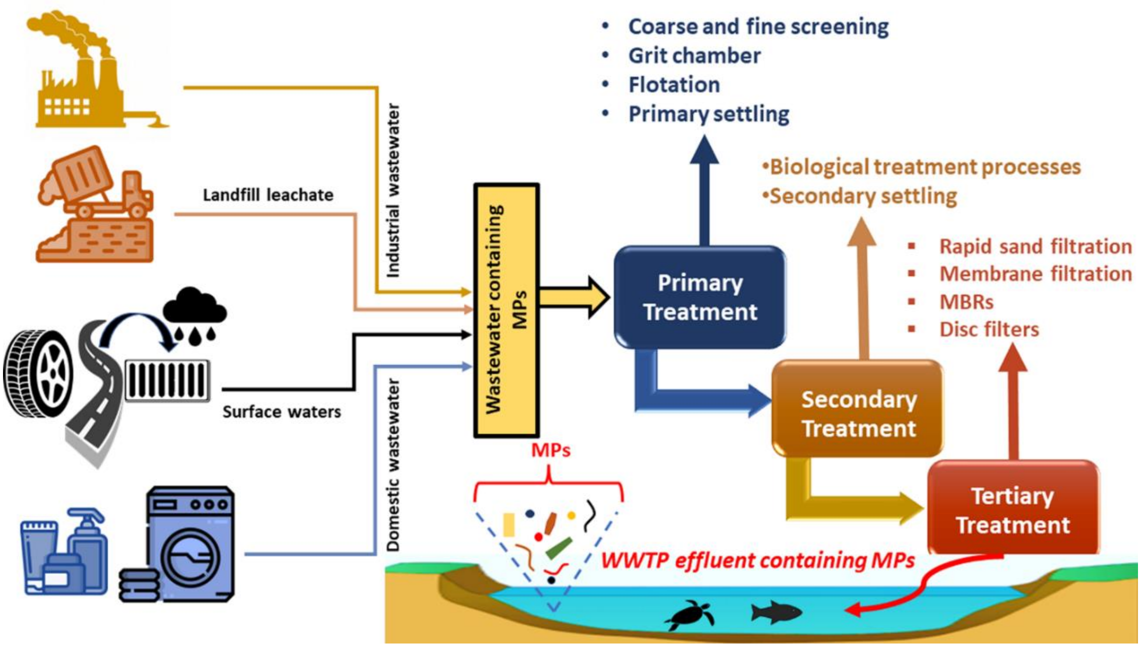
2.5 Wastewater sector

Context

Wastewater treatment plants (WWTPs) are a major pathway for plastics from terrestrial sources to enter aquatic environments.[103] Wastewater with high concentrations of microplastics is the result of many sources and phenomena, including the use of personal care products with primary microplastics, as well as secondary microplastics from laundry machines water discharges, industrial equipment, atmospheric fallout, and urban runoff connected to WWTP (dust, road-associated microplastic particles [RAMP], artificial grass, cigarette filters, etc.).

WWTP remove these MPs (along with other suspended solids) through primary, secondary and tertiary treatment methods (Figure 7).

Figure 9 - Microplastics sources in wastewater treatment plants and treatment stages



Extracted from: https://doi.org/10.2166/wst.2023.022.

The removed MPs will then accumulate in the sludge and be subject to later solid waste management, while the water effluent will be discharged into receiving water bodies. Ideally, the discharged water should be totally free of contamination, yet a complete cleaning is considered inconceivable,[104] and these discharged waters will normally present some level of MP contamination. The removal efficiency varies with different wastewater treatment techniques, and this may be a central element for the establishment of leakage factors.

In addition, areas with combined sewer systems (wastewater and rain runoff) can discharge untreated wastewater into rivers during excess rainfall- and event known as combined sewage overflow (CSO), which entails greater amounts of MPs running

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[103] https://doi.org/10.1016/j.jclepro.2019.03.321
[104] https://www.jstage.jst.go.jp/article/emcr/1/0/1_20200006/_html/-char/ja

directly into aquatic environments.[105] Increased precipitation due to climate change is likely to exacerbate CSO wastewater releases.[106]

Likewise, the application of paints to prevent corrosion in WWTP tanks may release further MPs into wastewater, creating undesirable additional MP contamination in wastewater.[107] Leakages in the structures (pipelines, containers, etc.) of WWTPs might be another source of plastic pollution within the wastewater sector, however no concrete discussion was found on this, suggesting that these losses might be marginal.

Potential plastic pollution points

Two main pathways were identified as potential sources of plastic pollution in the wastewater sector: effluent discharges, which could be characterized by removal efficiency rates; and sewer overflow during rainfall events, which may require an analysis of rainfall patterns vis-à-vis the volumes of water released during such events.

Related methodologies

Material flow- and measurement-based WWTP removal efficiency rates in WWTP

UN Environment (2018). Mapping of global plastics value chain and plastics losses to the environment (with a particular focus on marine environment)

SDG indicator metadata 6.3.1

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105 https://www.jstage.jst.go.jp/article/emcr/1/0/1_20200006/_html/-char/ja
106 https://news.mongabay.com/2022/01/innovative-sewage-solutions-tackling-the-global-human-waste-problem
107 https://doi.org/10.2166/wst.2023.022

2.6 Solid waste management

Context

For the proposed toolkit, we suggest organizing this section according to the following phases of solid waste management (Figure 10), aiming to enhance the understanding of how each stage contributes to plastic pollution:

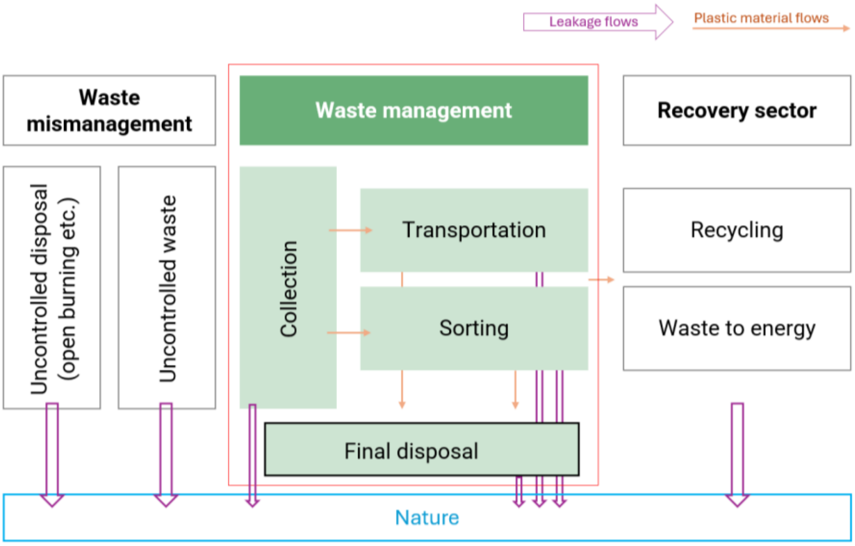
1. Waste collection: refers to gathering waste materials from various sources, such as households, businesses, and public spaces, for the purpose of transport to treatment or disposal facilities[108];
2. Sorting: involves categorizing plastics using both manual and mechanical methods based on type, volume, and other characteristics;
3. Transportation: moving plastic waste from collection points to treatment facilities or final disposal sites;
4. Disposal/End of Life: The final stage encompasses how plastic waste is managed at the end of its lifecycle for final disposal.

The type of waste collection systems varies across different contexts (urban or rural areas, e.g.) and sectors or activities (local solid waste management system, commercial waste, industrial waste, construction debris, hazardous materials, among others). In higher-income regions almost all MSW is collected, while less than 40 per cent is collected in lower-income countries.[109]

The collection methods can be organized through various systems, such as door-to-door, where bins or sacks are picked up directly from residents' doorsteps, or curbside collection, referring to the collection from designated locations for collective disposal. The configuration will vary widely, ranging from a single bin for mixed waste to multiple separate bins or sacks designated for different waste streams, and this is determinant to estimate/measure the proportion of plastic waste within MSW.

[108] According to expert recommendations, informal collection is a relevant phenomenon that also may require further discussion within the Working Group
[109] https://wedocs.unep.org/20.500.11822/44939

Figure 10 – Phases of solid waste management source category



Developed by the project team.

The sorting stage is where plastics (and other materials, according to market demands) are separated from overall waste, often through capital-intensive processes to identify as much as possible the most valuable recyclable materials, which will vary according to local contexts (Table 4).

Transportation can be divided into transport for collection purposes, normally to transfer or recovery facilities, and transport from transfer centers to final disposal (or thermal treatment).

Table 4 - Collection and sorting processes differ by country income level

	Low-income countries	High income countries
Collection	• Only partial coverage of public waste collection in cities and almost none in the countryside. • Informal sector plays a key role in collecting and sorting recyclables. • High-quality sorting achieved, but only for some high value streams such as PET.	• Municipal-led plastics recycling schemes are common. • Quality of sorting depends on local habits, collection facilities for recyclables and financial incentives. • Collection systems are highly mechanised.
Sorting	• Manual sorting is common. • Mechanical equipment limited to balers for compaction.	• Highly mechanised and capital-intensive facilities to maximise recovery of valuable plastics.

Source OECD (2022), Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options

As per final disposal, this toolkit will consider engineered and controlled landfills, including public (often municipal) as well as specific disposal sites (industrial landfills, healthcare, etc.). Incineration will only be considered if done in accordance with appropriate pollution control and monitoring measures[110] and with no energy recovery (these are considered under the recovery sector).

The management of municipal solid waste is usually the responsibility of local governments,[111] however in many countries, the informal sector and illegal activities are responsible for a good portion or most waste management activities. Other relevant

110 https://doi.org/10.5327/Z21769478968
111 https://wedocs.unep.org/20.500.11822/44939

actors are private companies involved in waste management systems and, of course, citizens, who are responsible for the initial stage of waste management (intention or requirement to dispose of plastic materials and products).

Potential plastic pollution Points

Plastic leakage and spillovers can indistinctly happen across the four stages of SWM, caused by similar or analogous processes, such as:

- handling of bags and bins during collection,
- loading or waste compaction in waste collection trucks,
- transportation of waste,
- unloading of waste materials either in recovery facilities or final disposal sites,
- transfer, storing and handling of plastic waste within recovery/treatment facilities,
- structural failures in landfills, leading to plastic releases to the environment.

Certainly, many other PPPP could be identified from a thorough analysis of waste management activities, yet it might be unfeasible to exhaust the number of possibilities. Fortunately, however, there are a wide number of indexes and methodologies dedicated to identifying and quantifying plastic leakage specifically in the waste sector, and they may be the best option here to characterize the leakage factor.

As an annex a set of categories and values are presented in order to build emission factors for the Solid Waste Management. These coefficients have been identified through a literature review and are presented as a proposal to be analyzed by the Working Group. These categories and values are organized around the four stages described above and present a simplified proposal for characterizing performance values.

Related Methodologies

UNEP-IUCN National Guidance for Plastic Pollution Hotspotting and Shaping Action

The WASTE WISE CITIES TOOL offers guidance on how to estimate plastic leakage in cities (Step 7.3), in line with GIZ's Waste Flow Diagram, using Material Flow Analysis assessment. A relevant concept of the Waste Flow Diagram is "leakage influencers", that presents "leakage factors" and "fate factors".

ISWA Plastic Pollution Calculator combines three types of data inputs: 1. Primary data user input questions on the waste management specifics of that area (e.g., waste characterization studies, household surveys, landfill tracking, interviews, litter surveys, waste plans); 2. Literature data to provide country or income level "default" values where other information is not available; and 3. Expert-reviewed leakage factors that relate leakage probabilities by specially designed algorithms.

Plasteax database provides a comprehensive snapshot of the plastic situation, offering specific information on various indicators such as managed waste (including incineration and sanitary landfill), recycling and mismanaged waste (including uncollected, dumped and littered), and leakage (direct) into ocean and waterways. Plasteax data offers highly specific data that can be tailored to individual countries, polymer types, applications or any combination of these for different scopes: Sectors (Packaging, Textile), Polymer and Category.

Global Plastic Action Partnership's National Analysis and Modelling tool

GPAP is a multistakeholder platform hosted as the Wold Economic Forum. Its approach is used to assess national plastic pollution and estimate the amount of plastic waste entering the oceans. The tool, National Analysis and Modelling (NAM) can predict plastic waste flows and leakage in the environment up to 2040. It is applied collecting national data but it includes preloaded data from Breaking the Plastic Wave (which maps countries to three income archetypes) and from PLASTEAX database for some countries. The tools allows to display the current situation in the country, baseline, and then model different future scenarios (Business as Usual, Upstream, Downstream, System change, and a range of Custom scenarios) by combining different action levers from the following categories: Reduce & Substitute, Redesign, Collection & Sorting, Trade control, Recycle, Disposal, and Mismanaged.

The Basel Convention has developed additional practical guidance for creating inventories of plastic waste. This guidance is intended to assist the Convention's parties in their annual reporting. Two of these methodologies are used to estimate plastic waste generation (the product lifetime approach and survey approach), while the third focuses on mapping the flow of plastic waste (Material Flow Analysis).

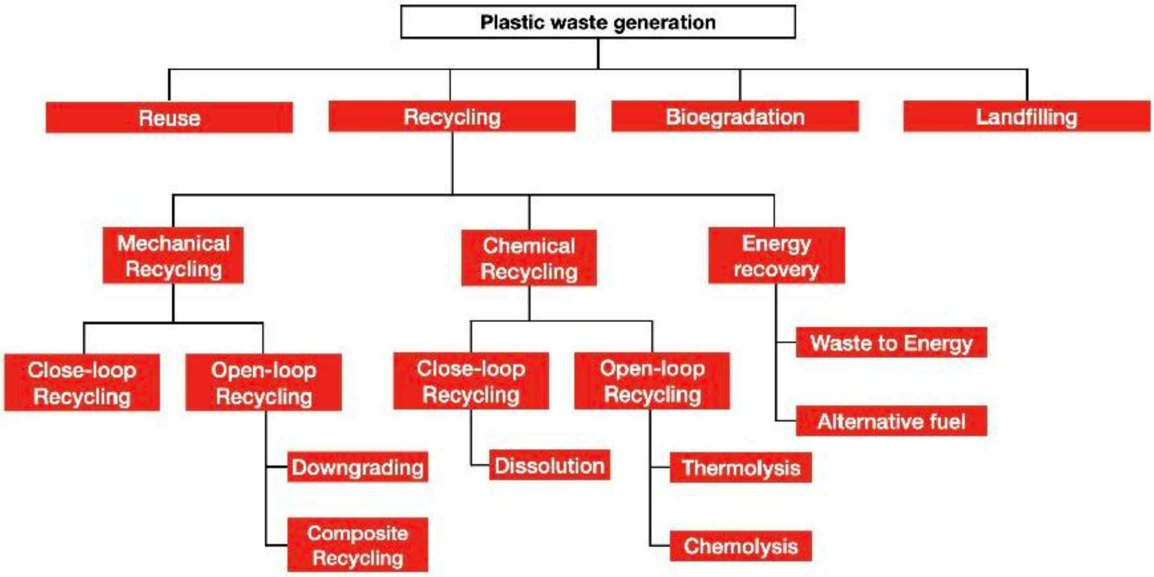
2.7 Plastic recovery sector

Context

Plastic materials are considered to become waste in the moment there is an "intention or requirement to be disposed of".[112] Against this, plastic recovery refers to the processing of plastic waste materials to be used again or continuously, either for the original or for other purposes, including energy recovery.[113]

A wide array of processes and techniques allow the recovery of such waste materials, either through value-retention mechanisms or material conversion processes.

Figure 11 –Classification of plastic waste management methods



Source: https://wedocs.unep.org/20.500.11822/46065

Value-retention mechanisms can be represented by refusing, reducing, reusing, repairing, refurbishing, remanufacturing, repurposing and recycling techniques[114], and these may or may not entail material conversion, which can be done through mechanical, physical, chemical and biological processes.[115]

The International Organization for Standardization[116] divides plastic waste recycling in three types: mechanical, chemical and energy recovery (Figure 11), and these ones can be further broken down into diverse sub-categories, depending on the kind and level of categorization one wants to apply.

For the purpose of this toolkit, mechanical and waste recycling and waste-to-energy (energy recovery) will be considered, given that our conceptual framework puts wastewater and waste management as the sectors where materials will be received

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112 https://unece.org/statistics/publications/conference-european-statisticians-framework-waste-statistics
113 https://www.iso.org/standard/45089.html
114 https://www.unep.org/circularity
115 https://wedocs.unep.org/20.500.11822/46065
116 Guidelines for the recovery and recycling of plastics waste https://www.iso.org/standard/45089.html

from. Under this rationale, the other recovery processes (refusing, reducing, reusing, repairing, refurbishing, remanufacturing, repurposing) are assumed to take place somewhere else in the plastic value chain (Prevention technologies, in Figure 12), before intention or requirement to dispose of plastic materials -in other words, before becoming waste.

Figure 12 - Technology innovation in plastic waste management technologies

Source: UNEP Internal material, based on Dussaux and Agrawala (2022); and Helinski, Poor, and Wolfand (2021)

Under this scenario, plastics arrives in the waste recovery sector from wastewater and waste management sectors. Part of it is recovered and the rest may go to final disposal (waste management sector back again). This category will consider the former (materials to be recovered) as the central element for mechanical and chemical recycling, whereas waste-to-energy will be accounted by incineration plants presenting appropriate pollution control and monitoring measures, according to international guidelines -e.g. Basel Convention[117], UNEP-IETC[118] or ISWA[119].

The division of recycling techniques (Figure 11) into further subcategories could be endless, since it is difficult to consolidate all chemical reactions, industrial processes, material treatment, etc. in a comprehensive way. In addition, many of these processes are registered as industrial properties, adding more complexity towards a complete outlook. Therefore, we assume that the second level of division (mechanical, chemical, energy recovery) might be enough for the purpose of this toolkit.

It is worth to mention, though, that informal and illegal activities represent a significant part of plastic materials flows in the sector (in the entire plastic value chain, actually). Despite these activities are difficult to characterize and measure, efforts will be made to try to incorporate this dimension as much as possible in the model, in a coherent manner.

[117] https://www.basel.int/Portals/4/download.aspx?d=UNEP-CHW-OEWG.12-INF-11-Rev.2.English.pdf
[118] https://www.unep.org/ietc/resources/toolkits-manuals-and-guides/waste-energy-incineration
[119] https://www.iswa.org/knowledge-base/iswa-guidelines-waste-to-energy-in-low-and-middle-income-countries/?v=24d22e03afb2

Potential plastic pollution points

Since collection and transportation are covered under waste management, the main PPPP within the recycling sector concerns to the separation and preparation of materials and the recycling processes per se, including the conversions of materials and residual disposals.

Separation and preparation of materials

Plastic waste coming to plastic recycling facilities is normally not properly packed or arranged as it would be the case with new materials/products. Hence, plastic pollution is expected to occur during the receiving and initial sorting of materials in recycling facilities, mostly through the dispersion of non-sorted materials, either through the air or through land and aquatic pathways.

Recycling processes

The three classes of plastic recycling present inherent risks of plastic leakages throughout their entire recycling processes. Mechanical recycling may present more risks of microplastics dispersion, since abrasion and friction processes -washing, shredding, etc.- tend to generate a significant amount of microplastics.[120]

Chemical recycling, in turn, may present more risks of plastic pollution through airborne dispersion or liquid spillages, since heating and melting are central elements in the technique. Finally, plastic pollution from energy recovery will be majorly identified in the smoke and ashes from the burning of plastics.[121]

Material recovery rates for the three types of recycling may be the starting point for the estimation of leakage factors. Additional or more granular information may be incorporated to this (for instance, plastic leakage factor for mechanical recycling of PET with plastic waste bales in certain state), but this will require an analysis of added complexity in relation to the toolkit operability.

Disposal of materials

Once recycled products or materials are finished, companies need to dispose of the production wastes, including trial and failed batches. Ideally, these waste materials should be directed to final disposal (either through the waste management sector or recycling companies themselves), yet that might not be the case, especially for small companies and informal/illegal recycling operations. It may be difficult to get specific data on this regard, nonetheless, and MFA might be helpful for overall estimations.

As an annex a set of categories and values are presented in order to build emission factors for the Recovery sector. These coefficients have been identified through a literature review and are presented as a proposal to be analyzed by the Working Group.

Related methodologies

UNEP-UICN National Guidance for Plastic Pollution Hotspotting and Shaping Action

WASTE WISE CITIES TOOL

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120 https://www.nature.com/articles/s44296-024-00024-w
121 https://www.sciencedirect.com/science/article/pii/S0048969720380141?via%3Dihub

ISWA Plastic Pollution Calculator

Plasteax database

Global Plastic Action Partnership's National Analysis and Modelling tool

3. Final thoughts

This Guiding Document V.1 presented a proposal for the initial conceptual framework of a toolkit to identify sources and estimate plastic pollution from sources, and the scientific basis to sustain it as well as proposals for coefficients and emission factors for the Solid Waste Management and Recovery sectors. The next steps are mostly related to advance on the identification of values of reference and emission factors for all the proposed sectors.

For more guidance on the review process, you may consult the "Note for reviewers" at the beginning of the document, as well as Annex 1, which brings more details about next activities and tentative timeline.

Meanwhile, the project team (below) will remain always available for further clarifications.

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

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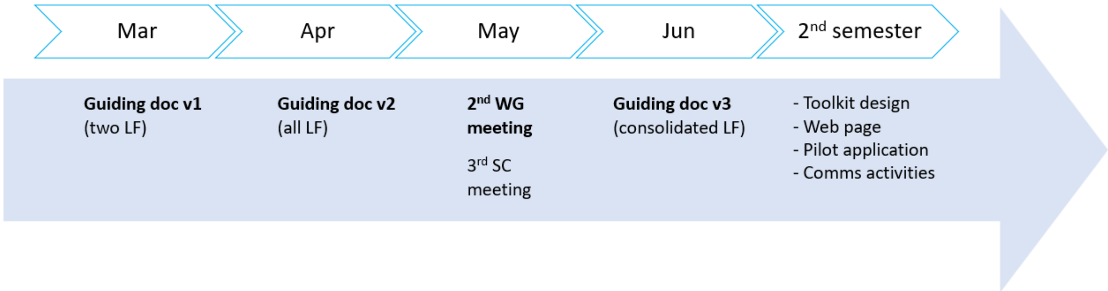
Annex 1 – Working plan.

The following diagram synthesizes the process ahead for the development of the toolkit. It highlights the most relevant milestones. Between the milestones we propose holding a set of virtual calls with WG members. These calls and meetings are being arranged according to the participants' expertise (e.g. statistics, Material Flow Analysis, Modelling, Waste Management, etc.).



Annex 2 Proposal of Plastic Leakage Factors

Development of leakage factors

The process for the construction of leakage factors for each source category is reported below, with a detailed explanation of the rationale for each proposed leakage factor and development of formulae. Many of the ensuing assumptions and choices will be necessarily selective, which tends to generate oversimplification and information losses. We try to make sure that the quantity, quality and effectiveness of information gained from our arbitrary choices outweighs the depravations of preceding suppositions.

1. Solid waste management sector

The purpose of this section is to present proposals for categories and reference values or coefficients that may help define Plastic Lackage Factors[1] for the Solid Waste Management sector, based on the literature and methodologies review carried out within the context of the project.

A first proposal consists of values that can be applied to the largest number of countries and contexts, considering, among others, the limitations in terms of availability of information and other data restrictions. Most of reference values and coefficients presented here are based on WFD Methodology and SPOT model as well as other sources.

In parallel, values (or emission factors) will be presented that can consider the existence of more specific data and, therefore, provide more precise estimations. Additionally, comments and questions on each value are added for the consideration of Members of the Working Group.

In the case of solid waste management, the coefficients are structured around the 4 main categories presented in this Guiding Document V.1 (Formerly called "Scoping Document").

1. **Waste collection:** refers to gathering waste materials from various sources, such as households, businesses, and public spaces, for the purpose of transport to treatment or disposal facilities;
2. **Sorting**: involves categorizing plastics using both manual and mechanical methods based on type, volume, and other characteristics;
3. **Transportation:** moving plastic waste from collection points to treatment facilities or final disposal sites;
4. **Disposal/End of Life**: The final stage encompasses how plastic waste is managed at the end of its lifecycle for final disposal.

Overall equation

In order to estimate plastic leakage within the SWM process, the general equation assumes that plastic losses/leakage in MSW are made up of the total plastics generated as waste multiplied by the sum of the percentages of loss/leakage in each of the 4 stages mentioned (Waste collection, Sorting: Transportation: Disposal/End of Life).

Plastic Leakage in SWM = Plastic generation in Solid Waste X (PL in Waste collection + PL in Sorting + Transportation + Disposal/End of Life)

*PL*SWM= Psw X (*PL*WC+*PLS*+*PL*T+*PL*D/EoL)

Where:

*PL*SWM= Plastic Leakage in Solid Waste Management

*P*sw = Amount of Plastic in Solid Waste

*PL*WC = Plastic Leakage in Waste Collection

PLS = Plastic Leakage in Sorting

*PL*T = Plastic Leakage in Transportation

*PL*D/EoL = Plastic Leakage in Disposal and/or End of Life

In relation to the basic information required for the estimation, the main data is the following:

- Total Waste generation
- Plastic amount (or percentage) in Solid Waste composition
- Rate of Collection coverage
- (Ideally) Rate of informal collection, sorting, transport and disposal

After characterizing the amount of waste generated, its composition (in terms of percentage of plastic as a component) and the rate of collection, the following categories and values can help to estimate Plastic Leakages across the Solid Waste Management process.

The suggested values are a simplification of values from the WFD. This simplification has been made selecting and proposing only three basic levels of plastic leakage (Low – Intermediate and High) at each stage of the SWM process.

It is important to mention that, even at high levels of collection, in some contexts, formal collected waste ends up in uncontrolled sites or unmanaged/mismanaged.

Table. Suggested categories and values. Source: simplification of WFD values.

a. Plastic Leakage in Waste Collection (%)	b. Plastic Leakage in Sorting (%)	c.Plastic Leakage in Transportation (%)	d.Plastic Leakage in Disposal and/or End of Life (%)	Total Plastic Leakage in SWM (%)	Total Plastic Leakage in SWM (Tn)
Formal systems Low = 2 Intermediate=5 High=10	Formal systems Low= 0 Intermediate= 7,5 High= 15	Formal transportation Low= 0 Intermediate= 1 High = 2	Formal disposal Low= 0 Intermediate= 2.5 High= 5		
Informal systems Low = 10 Intermediate=40 High =80	Informal Systems Low=60 Intermediate= 70 High= 80	Informal Formal transportation Low= 5 Intermediate= 7,5 High= 10	Informal disposal Low= 10 Intermediate=20 high= 30		

As mentioned above, some basic information required for estimating plastic leakage at the Solid Waste Management stage: Total Waste generation, Waste composition and Rate of Collection coverage.

In case countries (or cities) do not count with data on one or more of the above-mentioned categories, the following from the Global Waste Management Outlook[2] can be used a as reference:

Table: Waste Generation/Collection Rate/ Plastic in waste composition by region.

Region	**Waste Generation (Kg/capita/day) 2020**	**Collection Rate 2020**	**Plastic in waste composition 2020**
Australia and New Zealand	1.46	93%	8 %
Central America and the Caribbean	0.93	83%	11%
Central and South Asia	0.39	37%	5%
East Asia	0.70	75%	12%
East Europe	1.04	96%	12%
Latin America	1.14	65%	10%
North Africa	1.13	51%	9%
North America	2.22	94%	12%
Oceania	0.95	34%	9%
South-East Asia	1.14	49%	13%
Sub-Saharan Africa	0.65	44%	9%
West Asia	1.14	65%	9%
Western Europe	1.46	97%	12%

Source: Global Waste Management Outlook 2024

Sources:

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

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2. Recovery sector

The leakage factor for the recovery sector will be developed around three sub-coefficients, one for each recovery technique brought in Figure 11 (mechanical and chemical recycling and energy recovery). Different approaches and rationalization are necessary for the estimation of such sub-coefficients, according to (mainly) the nature itself of each technique, as well as to available data and its potential applicability into the model.

In addition, it is also necessary to aggregate countries around overall features of plastic waste management and plastic recovery, assuming this will lead to more refined assumptions of leakage rates according to local circumstances. We recognize this exercise entails significant simplification and normalization of heterogeneous information, nonetheless it is our best proposal for a well-grounded yet simple and useful estimation.

Building on this, countries were separated around three groups, according to plastic waste mismanagement and plastic waste recycling rates. In addition, in harmony with the sub-coefficients proposal, we provided a proxy for the average breakdown of plastic recovery techniques in each group, based on countries' statistics (Table xx). Chemical recycling represented less than 1% of recycling techniques in virtually all the analysed cases, hence it will be excluded from our calculations, as its uncertainties do not compensate for such a tiny materiality.

Table– Categorization of countries for recovery sector leakage factor

Category	Regional coverage	Plastic waste mismanag.	Plastic waste recycling	Recycling techniques breakdown		
				Mech	Chem	Energy recovery
Advanced	US, Canada, EU+OECD Europe (Icel, Isr, Norw, Switz, Turk, UK), Aust, NZ, Jap, Kor	5.3%	8.8%	27%	-	73%
Medium	LAC, Non-OECD EU (Bulg, Croat, Cypr, Malta, Roman), Eurasia, MENA, India, Southern Asia	33.3%	2.4%	32%	-	68%
Basic	Sub-Saharan Africa	63.2%	5.8%	85%	-	15%

Figures are regional averages, based on OECD 2022. The breakdown of recycling techniques was further analysed against individual data and case studies for cross-check validation. Full analysis on Annex xx.

1. Overall equation

The equation below is the combination of the three proposed recovery techniques into a single formula. As depicted in table xx, chemical recycling is a technique with yet very scanty use by countries (usually entailing less than 1% of plastic waste recycling), therefore the overall equation will entail only mechanical recycling and energy recovery in its framework.

$LF_{\text{recovery sector}} = LF_{\text{mechanical recycling}} + LF_{\text{energy recovery}}$

1. Sub-coefficient for mechanical recycling

The sub-coefficient of mechanical recycling will be circumscribed to an overall representation of a plastic waste mechanical recycling facility (Figure xx), which normally involves processes like receiving, sorting, milling, washing, and pelletizing of plastic materials.[2]

The leakage factor can be estimated from a combination of top-down and bottom-up approaches, as illustrated in the equation ss below, where X is the input data and refers to the amount of plastic recycled in a certain region in a determined period, and PRPW refers to the overall estimation of plastic leakages during pre-recycling process (receiving, sorting, rejection), in function of plastic mismanagement rates; whereas y, z, k… entail independent variables and refer to additional leakage points along the recycling process within the recycling facility, in function of X.

EQ. ss LFmr = Pre-recycling plastic leakage + additional leakage points (y, z, k…)

LFmr = PRPL + X (Xy, Xz, Xk)

PRPL is estimated from the amount of plastic waste in pre-recycling processes applied to plastic waste mismanagement rates. This estimation can be quite diverse, depending on the sort of recycling technique in addition to the plastic types being recycled and —maybe the most important— the quality of the waste streams.

Jeswany et al. (2021) ascertain that the losses during sorting and separation in mechanical recycling of mixed plastic waste are assumed to be 33.5%, validated by a sensitivity analysis run by the authors, and very similar to what Lase et al (2022)[3] estimated from a material flow analysis on a conventional and (so called) quality recycling processes of polyethylene and polyolefin films.

Plastic recycling volumes in 2022 in Europe also showed similar values (c.30%) of losses of plastic waste after sorting process,[4] while Arena (2005)[5] found that 24% of PET and 12.5% of PP materials entering plastic recycling plants in Italy becomes scrap, whereas in Japan, about 20% of plastic waste inputs to material recycling facilities are found to become residue.[6]

Cognizant of these variations, we decided to select the European case (30%) as our best proxy, not only because it represents the widest case study but also because it comprehends a more diverse range of plastic materials and recycling techniques; and it is yet a median value amidst the broad range of referred studies.

Equation yy illustrates how to calculate PRPW deducting this estimate from the inputs of plastic waste getting into a recycling facility (TPW); whereas equation zz can be used in case the output —recycled plastics, RP— is the only known variable. In this case, the material recovery efficiency rate[7] is applied to estimate TPW, thus allowing the calculation of PRPW.

Eq. yy $$PRPW = TPW - 30\%$$

Eq. zz $$TPW = \frac{RP}{0.7}$$

Finally, PRPW will be the independent variable that, when applied to plastic waste mismanagement rates (Table xx), will render the estimates of plastic leakages during pre-recycling processes (PRPL). Additional leakage points across the recycling processes are then captured through the additional independent variables (x, y, z…), according to information found in literature.[8]

2. *Sub-coefficient for energy recovery*

(to be developed)

Appendix - Literature to be analysed

Studies to look for data points (to fill in table ss and add to the overall equation of recovery sector):

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