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Plastics materials flows in the EU-27 and their environmental impacts

Unveiling the European plastic value chain

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Contents

Abstract

In this report, a Material Flow Analysis (MFA) model was developed for the 2022 EU-27 plastic value chain. The MFA boundaries included all the key steps of the value chain from production to end-of-life and recycling, covering 9 sectors and 15 polymers. Specific plastic flows typically less explored in literature were studied, including plastic imports and exports along the value chain, plastic losses into the environment as well as plastic waste mismanagement. Notably, the granular data collected enabled the modelling of bio-based plastic and biodegradable plastics flows, together with the exploration of plastic chemical recycling processes. The variety of collected data at the level of polymers and sectors were combined to generate product-specific results, thoroughly discussing the associated modelling challenges. Further, the interactions with stakeholders, improved and deepened the knowledge of the various interlinkages of the EU plastic value chain and enabled a finer modelling of polymers-specific and sectors-specific flows. Additionally, the MFA was combined with a Life Cycle Assessment (LCA), unveiling the value chain impacts across 16 impact categories, including but not limited to Climate Change. On top, a flexible and replicable methodology combining sectors-specific and polymers-specific estimates to obtain products-specific results was discussed. Such approach could also potentially be applied to other product-specific MFAs even beyond plastics. The LCA followed the Environmental Footprint 3.1 method recommended by the European Commission. Results underlined that the EU-27 plastic production amounted to 57.9 Mt in 2022, with only 1.1% of the total needs being covered by bio-based plastics. The results highlighted the dominance of the Packaging sector, being 33.9% of total plastic consumption. Despite 36.6 Mt of waste being properly collected (86% of waste generated), significant quantities of plastics were either lost or mismanaged along the value chain, accounting to 6.6 Mt (11.4% of the total EU production). The average EU-27 end-of-life recycling rate was 19.6%, mostly due to mechanical recycling activities (and a negligible contribution of chemical recycling). The LCA study revealed that more than 252 Mt_{CO_2} eq. were emitted along the life cycle of the 2022 EU plastic value chain[1], considering all flows connected to plastic consumption in the EU. The Packaging sector contributed to around 29% of the total impacts, with a striking importance attributable to the production and manufacturing stages (representing 79% of Climate Change impacts). This study represents a key milestone in improving granularity and details of complete overviews of plastic flows in the EU and the findings emphasizes the need for improved data generation, collection, harmonization, and the establishment of proper monitoring frameworks to assess the implementation of EU recycling targets and boost the circularity of the plastic value chain. The developed methodology offers a flexible tool potentially applicable to other value chains, even beyond plastics. This report provides insights for decision-makers, researchers, and other stakeholders to show areas for potential improvement and support the shift towards sustainable plastics.

[1] Impacts from plastics consumed in the EU, corresponding to approximately 14% of total impacts from global plastics production as estimated by Organisation for Economic Co-operation and Development studies (OECD, 2019).

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1 Introduction

1.1 Background

The global production of plastics has recently peaked, exceeding 400 Mt in 2022, more than twice the quantity produced in 2000 (Statista, 2024; OurWorldInData, 2024). The unique properties of plastic, including versatility, durability, light weight, and cost-effectiveness, have made it a crucial part in various industries such as packaging, automotive, and electronic. As a result, plastic products have become ubiquitous in the European Union (EU) economy (Plastics Europe, 2024). The production of plastic has a significant impact on the EU's economy, supporting millions of jobs and generating considerable revenue. With a per capita plastic consumption of around 100 kg in the EU (Organisation for Economic Co-operation and Development – OECD, 2022; Amadei et al., 2021), the importance of the plastic value chain is clear. Looking ahead, the OECD (2022) predicts that the EU's plastic consumption will double by 2060, underscoring the material's continued growth and significance.

The pervasive use of plastic, however, has significant environmental implications, particularly with regards to plastic pollution, littering, and greenhouse gas emissions (European Environment Agency – EEA, 2024a). The global environment is increasingly polluted with microplastics, which are plastic debris smaller than 5mm, as well as macroplastics, which are larger pieces. Microplastics are commonly released during the use stage of plastic products, generated through the breakdown of littered items, or lost during other life cycle stages such as waste management. Once released into the environment, microplastics tend to persist and can be transferred through food chains, potentially leading to human ingestion (EEA, 2024a; Amadei et al., 2022). The annual release of microplastics in the EU is estimated to be between 0.7-1.8 Mt (EC, 2023a). Furthermore, as the production of plastic products continues to grow, so do the associated greenhouse gas emissions (OECD, 2022). The plastic value chain significantly contributes to these emission as a consequence of fossil fuels used in the production and manufacturing life cycle stages, which accounted for approximately 200 million metric tons of CO_2 equivalent emissions in the EU in 2020 (EEA, 2024a; Tenhunen-Lunkka et al., 2023). This highlights the need to address the environmental impacts of the plastic value chain, particularly considering the expected growth in plastic production and consumption.

The concept of a circular economy is a key strategy for mitigating the environmental impacts of the plastic value chain, both within the EU and globally (EC, 2020; EEA, 2024b). At its core, a circular economy involves a system where materials are continuously cycled back into production through processes such as reuse, refurbishment, and recycling, thereby decoupling economic growth from the consumption of non-renewable resources (EMAF, 2024). Despite its significant potential benefits and importance, the adoption of circular economy principles in the EU plastic value chain is progressing at a too slow pace for achieving EU targets. For example, the EU plastic recycling rate (calculated as a ratio between recyclates produced and waste generated) is estimated ranging between 14% and 25% depending on the sector/polymer under scrutiny (Amadei et al., 2022; Antonopoulos et al., 2021; Lase, 2023), due in part to inefficiencies in plastic waste collection and management systems or contamination/low quality of recyclables. While the capacity of plastic recycling facilities in the EU has increased more than fivefold since 1996, reaching a significant milestone by 2021 (EEA, 2024a; Plastics Recyclers Europe, 2021), the rate of improvement in plastic waste collection has not kept pace. To achieve a truly circular economy, secondary plastics need to be used into new products. However, less than 10% of the total recycled plastics are being used in new products or product elements (EEA, 2024a; Plastics Europe, 2024), although variations on the result could be associated to specific polymers.

In response to the environmental challenges posed by plastics, the EU has introduced a set of policies aimed at promoting sustainability and reducing environmental harm. These policies include the European Green Deal (European Commission – EC, 2019a), the EU Plastics Strategy (EC, 2018), the Single Use Plastic Directive (EC, 2019b), and the EU Regulation restricting intentionally added microplastics (EC, 2023b). The primary goals of such policies are to boost recycling rates, encourage the development of sustainable alternatives, and mitigate the environmental impacts of plastic waste and microplastics. Additionally, the EU is actively engaged in international efforts to combat plastic pollution, including the high ambition coalition to set up a global plastics treaty aimed at ending plastic pollution by 2040 (Plastics Europe, 2024). This initiative aligns with the United Nations' Sustainable Development Goal (SDG) 14, which seeks to conserve and sustainably use oceans, seas, and marine resources (UNEP, 2024). To achieve true circularity in the plastics sector, it is essential to adopt an integrated approach that includes the entire lifecycle of plastics, for example reformulating materials' compositions (e.g., additives, fillers, coatings), extending the lifespan of plastic products, or enhancing collection and sorting efficiencies.

1.2 Objectives and novelty of the study

To support the implementation of the cited policies and strategies, this report aims to unveil the European plastics materials flows for the key economic sectors and polymers, analysing the total emissions of the EU plastic value chain from raw materials to end of life of products. Ensuring the competitiveness of the EU and achieving its ambitious policy targets, require a comprehensive analysis of the EU value chain. Numerous studies have highlighted the potential of Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) to contribute significantly to these efforts. Therefore, this report provides an in-depth examination of these two approaches, as well as their combined application, to inform and support the development of effective strategies for the EU value chain.

This study aims at showing a mass flow model for the whole value chain of plastics in the EU-27 for the year 2022, from pellets production to end-of-life plastic management (referred to in this report as 'the 2022 MFA'). The 2022 MFA aims at reviewing, consolidating and refining the existing JRC material flow model for the EU-27 2019 (Amadei and Ardente, 2022); referred to in this report as 'the 2019 MFA'). The 2022 MFA model includes details for a total of 9 sectors[2]. Such refinements benefited from the insights collected through the support stakeholders, especially discussed during a stakeholders' consultation (further described in Section 2.2). For these abovementioned sectors, detailed information is provided on 15 specific polymers, including 12 fossil-based polymers[3] and 3 bio-based polymers[4]. Additionally, two general categories (i.e. 'Other fossil-based polymers' and 'Other bio-based polymers') are included in the analysis to map the remaining fossil and bio polymers not specifically detailed.

While MFA allows for the quantification of all plastic flows in a system, providing information on whether a circular economy could help mitigating environmental impacts is also fundamental. The LCA methodology could provide impacts insights, especially allowing measures of benefits and burdens associated with a defined product life cycle system. Coupling MFA with LCA ensures a deeper understanding of the value chain impacts, especially those that might be neglected if only mass-related insights are explored. For instance, depending on the impact category under scrutiny,

[2] Namely: Packaging, Construction, Transport, Electronic, Agriculture, Textiles, Healthcare, Fishing and 'Other'.

[3] Namely: low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), expanded polystyrene (EPS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyurethane (PUR), styrene-based polymers (acrylonitrile butadiene styrene (ABS), polyamides (PA) such as nylon6 or nylon66, polymethylmethacrylate (PMMA), polycarbonate (PC).

[4] Namely: bio-polypropylene (bio-PP), bio-polyurethane (bio-PUR), cellulose acetate (CA).

LCA could unveil how less-relevant flows (mass-wise) could have instead a meaningful role in driving environmental impacts.

On the other hand, LCA could reinforce the importance of certain life cycle stages that were already identified as key stages thanks to MFA.

This report aims to:

- Assess the sector-specific and polymers-specific plastic flows within the EU-27 for the year 2022, not only detailing the demand for plastic manufacturing and consumed plastic, but also waste management and recyclates' production and fate, as well as modelling the main plastic losses to the environment along the value chain. Additionally, the study aims to assess two product-specific plastic flows within the EU-27 for the year 2022 leveraging the polymer-specific and sector-specific insights details (namely flat screen products and PET bottles);

- Assess the total emissions of the EU plastic value chain from raw materials manufacturing to end-of-life waste management and recycling, covering the 16 impact categories of the Environmental Footprint method, associating impacts to the EU 2022 MFA (as calculated in the present report) to identify the current environmental impacts of the value chain and to frame them in the context of implementation of circularity strategies.

To date, according to the authors knowledge, few-to-none studies have combined MFA with Life Cycle Assessment (LCA) to provide a complete overview of flows and impacts of the plastic value chain in the whole EU. This lack of analysis is particularly relevant for the whole EU territory especially when multiple sectors, life cycle stages and polymers are considered at the same time, as in the present study. Mapping the hotspots of material flows in the value chain alongside the associated environmental impacts can be key for identifying priority areas for intervention towards improved sustainability and circularity. Beyond unveiling the main data gaps and inconsistencies concerning available data (especially for less explored sectors, and life cycle stages) this study included several novel aspects compared to previous analysis, in particular:

- The interactions with stakeholders, specifically following a Stakeholder Consultation (held on April 2024) and a Workshop (held on December 2024), that improved and deepened the knowledge of the various interlinkages of the EU plastic value chain and enabled a finer modelling of polymers-specific and sectors-specific flows;

- The assessment bio-based plastic flows and biodegradable plastics, mapping production flows and potential end-of-life waste management routes (e.g., composting). Bio-based plastics are plastics that are entirely or partially derived from biomass, such as plants (e.g., starch, sugarcane, corn, etc.), microorganisms, or other renewable biological sources. Bio-based plastics can be classified into several categories, including biodegradable[5], compostable[6], non-biodegradable bio-based plastics and bio-based non bio-degradable plastics[7] (EC, 2022);

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[5] Biodegradable bio-based plastics (e.g. bio-PUR, bio-PP) can be degraded via microbial action by microorganisms into simpler molecules (e.g., water, carbon dioxide, methane, etc.).

[6] Compostable plastics (e.g. CA, PBAT) refer instead to a subset of biodegradable plastics that can degrade in specific 'composting conditions' (of temperature, oxygen, humidity, etc.) into simpler components.

[7] For instance: bio-PE, bio-PP and other similar polymers derived from renewable sources but that are not biodegradable.

- The analysis of waste plastic chemical recycling[8] processes, explored and mapped together with the traditional mechanical recycling[9] route for plastics waste, to unveil its role in the 2022 EU plastic value chain;
- The full assessment of polymer-specific plastic flows for all the 9 sectors under scrutiny and their combination with sector-specific analysis to generate product-specific ones. Notably, this study mapped flows associated with sectors and flow associated with polymers that were merged to generate results associated with plastic products, while simultaneously maintaining the mass balances of the flows. Especially this assessment enabled the identification of the key methodological challenges of coupling 'bottom-up' flows estimation (typical for polymer-specific insights) with 'top-down' ones (typical for sector-specific insights), proposes an approach to transparently highlight such differences while ensuring mass-balance;
- The study also aims to provide one of the first attempts at a full eagle-eyes ("snapshot") overview of the impacts associated with the whole EU-27 2022 (coupled with details at the level of sectors), describing and proposing a methodological approach to couple LCA with existing system-wide MFA data. Such findings represent a pivotal effort to provide reference estimates of the whole plastic value chain impacts across 16 impact categories, to support science-based policies.

Further, the methodology developed in the present report could also prove to be reproducible not only for the assessment of value chains specifically related to plastics, but also to potentially unveil flows and impacts of value chains associated with different materials and sectors towards unveiling their most notable sustainability, circularity and competitiveness aspects.

[8] Chemical recycling refers to processes where plastic waste is converted into monomers or other basic chemicals, through depolymerisation (via e.g. methanolysis, hydrolysis, glycolysis, etc.), solvent-based processes (via e.g. dissolution or precipitation) or thermal processes (via e.g. pyrolysis or gasification).

[9] Mechanical recycling refers to a process where plastic waste is physically broken down into smaller pieces, melted and then reformed into new plastic products without changing the chemical structure of the plastic.

2 Methodology

2.1 Overview of goals of the analysis

The MFA models developed for this study aim at detailing plastic mass flows (either expressed as megatonnes [Mt] or kilotonnes [kt]) along the main steps of the value chain of plastics. A "plastic flow" is here defined as a single flow at sector level (e.g., in the case of the Packaging sector, a "packaging plastic flow" stands for a general plastic flow for the "packaging" sector). Plastic flows might be composed of several polymers. A "polymer flow" is instead defined as a flow expressed directly at the level of specific polymers (e.g., in the case of the packaging sector, a "LDPE packaging plastic flow" stands for specifically a polymer flow for the "packaging" sector). On the MFA analysis, the key methodological approaches are presented in the following Sections:

- Section 2.4.1 – Overview of the logic of the sector-specific models, including the system boundaries and main assumptions. Sector-specific models are intended as material flow analysis model where the granularity detail of data is at the level of plastic sectors;
- Section 2.4.2 – Overview of the approach of the polymer-specific models, including its main assumptions. Polymers-specific models are intended as material flow analysis model where the granularity detail of data is at the level of polymers;
- Section 2.4.3 – Overview of the logic of the product-specific models. Product-specific models are intended as material flow analysis model where the granularity detail of data is at the level of polymers for a given plastic product in a given plastic.

Sankey diagrams visualizations (generated via an ad-hoc tool developed at the JRC) were employed for the sector-specific, polymer-specific and product-specific MFAs presented in the report (Section 2.4.1; Section 2.4.2; Section 2.4.3). The MFA results were also employed as the starting point to perform a Life Cycle Assessment (LCA) of the whole EU-27 plastic value chain, for the same 2022 reference year. The methodological approach of the LCA analysis is presented in detail in Section 2.5 (including for instance, goal and scope and functional unit, life cycle inventories, etc.).

2.2 Stakeholder consultation

On the 9th April 2024, the JRC conducted a workshop to collect feedback on the 2019 MFA model via a direct interaction with key stakeholders on the EU plastic industry cycle. During the workshop, results from the 2019 MFA were presented and key aspects to be improved were discussed. After the workshop, a questionnaire was circulated to the participants, in view of capturing any relevant information towards developing the 2022 MFA model. These findings were collected and scrutinised by the JRC, serving as priority information and building-block to establish a market-reality-adherent 2022 MFA model. Further details are provided in Annex 1.1

Following the workshop and the associated data collection, the JRC conducted a series of bilateral meetings to further explore specific aspects of the plastic value chain considered in need of improvements. These meetings took place in September and October 2024, with specific experts of the plastic value chain, also representing key EU industry associations. The interactions included exchanges about less explored sectors, such as healthcare and fishing, as well as discussions on specific cross-cutting topics, including for example plastic losses, mismanagement, and stock.

All the gathered data were compiled and complemented with literature findings to generate a set of preliminary results that were disclosed to stakeholders during an additional specific workshop, held on the 6th December 2024. During this event, the JRC presented the preliminary findings for the 2022 MFA at the level of the whole EU plastic value chain, together with in-depth sector-specific results' overviews. Results were discussed during the event allowing the JRC to capture any aspects in need of revision. Further, exceptional challenges identified by the JRC activities were underlined and examined with participants to unveil strategies to improve them in future MFAs (e.g., expanding knowledge of less-explored flows and sectors, unveil the type of imported plastics and differentiate imports of primary from imports of secondary plastics, etc.).

2.3 Literature review and data adaptation

To complement data collected during the consultation/exchanges with stakeholders, literature studies and relevant statistics in the field of the EU plastic value chain were also explored. This literature research focused on gathering documents devoted to the material flow analysis and life cycle assessments of plastics sectors, plastics polymers and plastics products in the EU. To this end, academic databases such as Scopus® (Scopus, 2024), Google Scholar (Google Scholar, 2024), and other similar platforms were scrutinized to find potentially relevant studies. This process was further enhanced via snowball literature collection, recognizing pertinent references cited within the first set of articles. Furthermore, gathered data were complemented through insights collected from the most reputable statistical resources and datasets provided by leading industry associations and authoritative bodies in the EU plastic field (e.g. Plastics Europe, 2024; Plastics Recyclers Europe, 2024).

In the 2019 MFA (Amadei and Ardente, 2021), data were adjusted when needed to the year and geography in scope via the Gross Domestic Product (GDP) (The World Bank, 2022), following a country-region-specific approach. This adjustment was applied to the data provided in the reference sources assessed considering the specific country-region-year of each of the retrieved numerical data. Despite adjusting data based on GDP is a valid approach, using plastic production volumes as a reference metric may offer greater precision, particularly in the case of countries such as the United Kingdom and Switzerland (as these nations show high GDP levels, and relatively low plastic production volumes). Consequently, in the EU-27 2022 MFA presented in this report, all data were adjusted based on the reference year and the geography in scope via specific plastic production volumes.

The annual plastic production data for each European country and year from 2000 to 2023 was retrieved from Eurostat (Eurostat, 2022). When sources provided data for the EU area including for instance other countries (such as United Kingdom, Sweden, etc.), it was necessary to precisely adapt them to the EU27 scope. In case of missing production data from Eurostat database, proxies were used to fill the gaps (e.g., as plastic production data were missing for the Norway geography, Sweden was used to represent it due to its similar geography and GDP). The collected data was then adjusted using correction factors calculated based on the reference year 2022 for EU-27 (Equation 1).

Equation 1. Correction factor calculation.

$$Correction\_factor_{i,j} = \frac{Plastic\_production_{EU,2022}}{Plastic\_production_{i,j}}$$

Where:

- Correction_factor_i,j: correction factor related to a specific country (i) and specific year (j);
- Plastic_production_EU,2022: quantity of plastic production for EU-27 in the 2022;
- Plastic_production_i,j: quantity of country-specific (i) plastic production in a specific year (j).

2.4 Material Flow Analysis overview

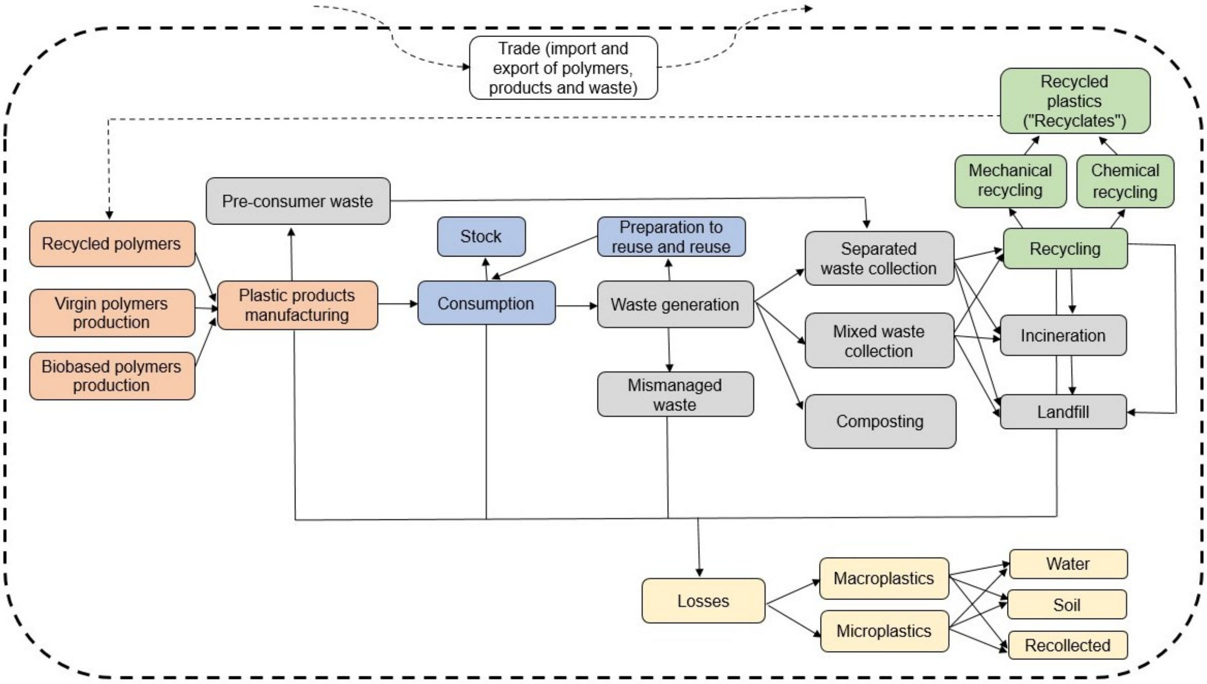
2.4.1 Sectors-specific modelling

The MFA model covered a comprehensive list of nine sectors: Packaging, Construction, Transport, Electronic, Agriculture, Textiles, Healthcare, Fishing, and 'Other' sectors (including heterogeneous plastics not accounted in the previously mentioned specific sectors). Additional details related to the specific definition of each sector, are provided in the 2019 MFA report (Section 2.3.1 of Amadei and Ardente, 2022) as the same sectors list is used.

The MFA model was developed by firstly identifying its specific system boundaries, detailing the various life cycle stages under scrutiny. Based on this, a set of a sector-specific Transfer Coefficients (TCs) matrixes were established, based on stakeholders' inputs and literature data. TCs are expressed as percentages and defined for each input and output flow of a process ensuring that the mass balance among life cycle stages is maintained. Further information related to TCs are provided in Annex 1.2, which outlines the methodology employed.
The TCs matrixed were developed using a 'top-down' approach. Specifically, the 'top-down' approach was used to model sector-specific flows, allocating the total production demand to individual sectors based on market data (see Annex 1.3 for further details). Furthermore, each sector was analyzed independently, with specific mass flows calculated throughout the various life cycle stages of each sector.

The system boundaries described in this Section are consistent across all sectors under scrutiny, to ensure comparability among them and consistency throughout the entire EU value chain analyzed. In Figure 1, a simplified overview of the system boundaries is provided. The same colour was used to visually differentiate among the major steps in the plastic value chain. Each box included in the MFA is considered a 'node' or 'step' of the plastic value chain. In the context of the present study, each 'node' could either represent: (i) a simplification of an industrial process/collection of multiple industrial processes (e.g. the 'separated waste' node refers to plastic waste separately collected and includes activities such as sorting and cleaning of plastic waste); (ii) a 'step/action' of the value chain, specific stage within the entire lifecycle of plastics (e.g. manufacturing, consumption).

Figure 1. Simplified diagram of the system boundaries included in the MFA model.



Source: JRC elaboration.

The system boundaries for this study also included flows related to alternative plastic feedstock (and their associated fate) together with emerging waste recycling pathways (e.g. chemical recycling, later detailed in this Section).

In fact, the modelled **plastic production** captures not only the demand of fossil-based virgin plastics, but also the one associated with bio-based polymers, including the import and export of such polymers. In the present study, bio-based plastics are included to account for polymers production derived from renewable resources, such as plants (e.g. corn, wheat). During the plastic manufacturing process, a certain quantity of **pre-consumer waste** may be generated. This stream was included in the boundaries of the present study, and its fate was detailed considering its high quality waste (Plastics Europe, 2021).

Concerning **plastics products manufacturing**, the 2019 MFA (Amadei and Ardente, 2022) distinguished between the manufacturing of 'semi-finished' items (i.e. that could be either used as inputs for other finished products or directly sold to consumers) and 'finished' items (i.e. directly sold to consumers). Following specific feedback provided by stakeholders during the consultation, this study presents instead a simplified overview of the manufacturing stage where both flows are aggregated (Annex 1.1). To ensure a broad and proper coverage of all plastics products in the EU, the information retrievable from the 2024 Plastics Europe report 'The Circular Economy for Plastics' (Plastics Europe, 2024) were employed, as this source provided recent and key insights on several stages of the EU plastics economy. Nonetheless, the scope of Plastics Europe (2024) was further adapted to fit the needs of the present study. In particular, the study of Plastics Europe (2024) excluded textiles plastic products and some additional plastic products (e.g. adhesives; mapped within the 'other' sector), that were instead mapped and considered in the present analysis (more details on this correction are provided in the Annex 1.3).

The **consumption of plastic products** in the EU territory arises from both imported product and products manufactured within the EU boundaries. Each sector-specific apparent consumption (i.e. calculated as plastic production minus products exports plus products imports) was estimated using the methodology outlined in the 2019 MFA (Section 2.5.1, Amadei and Ardente, 2022). After consumption, plastic products become waste and are discarded. In the present study, the consumed plastics can be disposed of as waste, lost in the environment, or kept in stock. Moreover, stock refers to a 'stock variation' since it was calculated as the difference between the 2022 yearly quantity of plastic consumed and the yearly quantity of waste generated from consumption (Annex 1.3). The ‘stock variation’ therefore accounts for the potential discrepancy between consumption and waste generation each year (due to e.g. different lifespans among plastic products).

On top of pre-consumer waste generating during plastic manufacturing process, the total quantity of **post-consumer waste** generated for each sector was calculated by aggregating 4 distinct flows: waste collected, waste exported, lost waste and mismanaged waste. The waste collected flows encompassed waste gathered by or on behalf of municipal authorities and managed by formal waste management systems. In contrast, exported waste included the portion which is shipped outside EU-27. Plastic losses, on the other hand, not only capture plastic amounts that are inadvertently lost or littered e.g. by consumers, but also losses events occurring during waste management or other life cycle stages of the plastic value chain. Losses ultimately accumulate into the environment (soil and water losses are accounted in the present analysis). Finally, mismanaged waste is here intended as waste which is inadequately disposed, and/or processed/treated and ways that could create routes for potential losses and releases/damages to the environment (further details in Annex 1.3).

The **waste collection** stage entails the management of waste which is separately collected (i.e., a waste stream almost entirely composed of plastics) or collected with other post-consumer waste types (i.e., mixed waste collection, of a fraction of waste that also includes plastics). These waste streams were assumed to be sorted and ultimately sent to incineration, landfill and recycling. On top, a flow of compostable plastic waste was also modelled in the present study and assumed to be collected separately and sent to composting facilities. In such facilities, naturally occurring micro-organisms degrade compostable plastics in a controlled ‘composting environment’. Notably, both fossil-based (i.e., polymers made from fossil fuels resources) or bio-based (i.e., polymers made from renewable resources) can be composted, depending on the specific polymer’s production process that was employed to generate them (EuRic, 2020). This study differentiated between bio-based compostable and bio-based not compostable plastics (details are provided in Annex 1.4).
A valuable fraction of waste collected could be ‘prepared for reuse and reused’. This flow includes the maintenance (e.g. repairing and refurbishing) of waste collected products. This flow was accounted for the Transport, Electronic and Textiles sectors (Annex 1.3). Compared to the 2019 MFA (Amadei and Ardente, 2022) the input data for Textiles and Transport were updated to reflect recent insights from Huygens et al., (2023) and stakeholder exchanges (Annex 1.1).

Plastic losses in the environment could occur during several life cycle stages, including losses during production and manufacturing activities, inadequate waste handling, improper disposal, and consumers behaviours, and because of the inherent durability of materials like plastics. Further, these factors are compounded by environmental conditions, such as wind and water, which disperse materials from managed systems into the environment. Losses related to littering events accounts for cases in which an intentional improper disposal of waste occurs (e.g. plastic items that are thrown away on-the-go). A detailed overview of the approach used to estimate losses and mismanaged waste along the value chain is provided in Annex 1.3.
Overall, the present study accounts for the releases of macro-plastics (intended as plastic debris of a dimension above 5 mm) and micro-plastics (intended as plastic debris of a dimension below 5mm) to the environment, and accounts for the soil and water final environmental sinks. Losses to air were excluded from the scope of the analysis, together with nanoplastic losses (in both cases, due to yet to be developed up-to-date scientific evidence on the topic). The fragmentation of plastic losses (i.e., macroplastic losses fragmenting into microplastic) was excluded as current knowledge on the phenomena hinders a proper accounting in the case of a yearly ‘snapshot’ overview, such as the one of the present study. The potential recollection of a fraction of plastic lost was also covered in the

present analysis, to account for activities such as informal waste picking or street cleaning that may redirect lost plastics to the proper waste disposal routes.

As previously noted, part of the collected waste is sent to **recycling facilities**, which includes all the processes aimed at reprocessing them into secondary raw materials in the form of granulates (including recycling facilities specific pre-treatments, such as sorting and cleaning of the incoming waste; Antonopoulos et al., 2021).
The present study distinguishes between mechanical recycling and chemical recycling. The term 'mechanical recycling' is typically employed to account for a technology not significantly altering the structure of the waste feedstock, resulting in recycled polymers that maintaining an intact chemical structure. By contrast, chemical recycling typically refers to a technology/set of technologies breaking down the plastic feedstock into its monomers constituents (such as depolymerisation) or into hydrocarbons via high-temperature processes (such as pyrolysis). The output of both recycling processes is referred to as 'recyclates' in the present study. Different amounts of recyclates are obtained depending on the specific recycling efficiency (which accounts for the any pre-treatment and for the input feedstock quality). Leveraging insights from Plastics Europe (2024) and Souder et al. (2024), the present study also mapped the specific 'fate' associated to recyclates. This refers to the sector in which a given recyclates may be employed to manufacture new plastic products. Such sector may in fact differ from the sector of origin of that specific plastic waste. As an example, recyclates generated because of recycling activities of Packaging products may be used to manufacture products destined to the Construction sector. On top, the fraction of exported recyclates was also modelled leveraging information from Plastics Europe (2024). Recycling residues were included and sent to either incineration or landfill (Annex 1.3).
The **incineration** (intended as incineration with energy recover) and **landfill** facilities are assumed to manage all the remaining waste flows and are intended as final disposal stages (further details are provided in Annex 1.3).

2.4.2 Polymers-specific modelling

The polymers-specific MFAs were established based on the sector-specific MFAs presented in Section 2.4.1. To develop these MFA models, the following steps were employed (Figure 2):

1. The existing literature for each polymer was reviewed, collecting the relevant sector-specific polymers' information to build polymers-specific flows for each sector (e.g. share of polypropylene employed in the Packaging). Additional insights were analysed with relevant information retrieved from stakeholders' feedback;

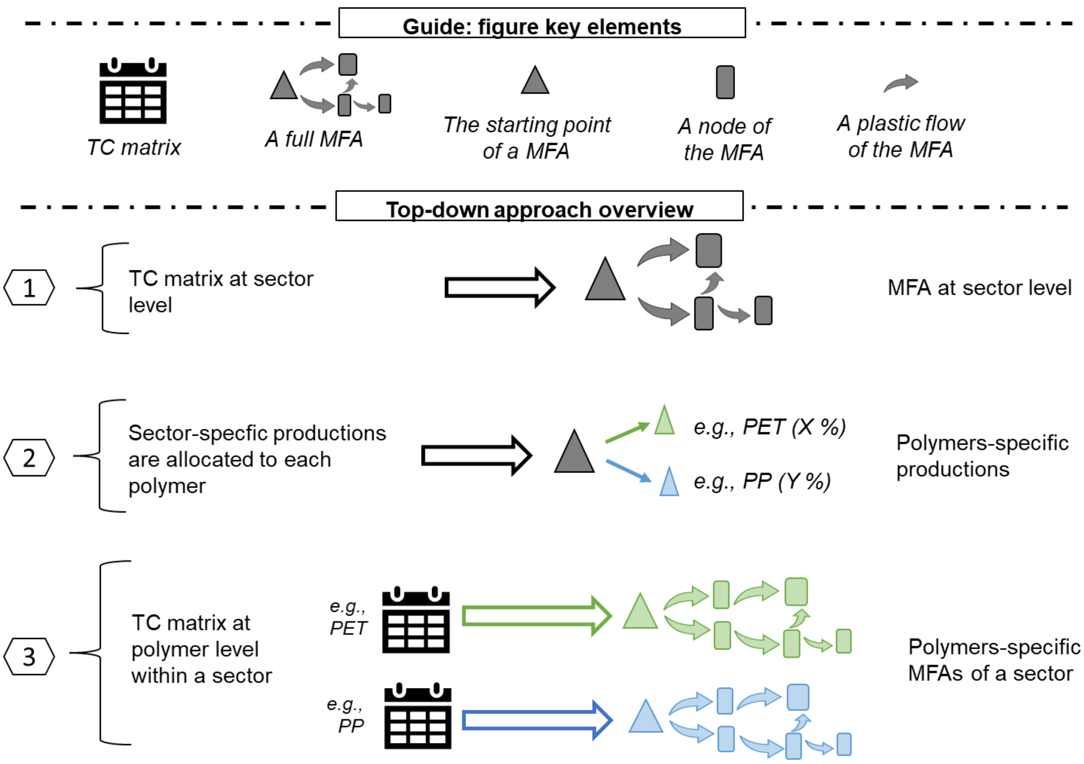
2. The total plastic production of each sector was allocated to the significant polymers within that sector. A set of MFA were developed for each sector, starting from these total polymers-specific productions;

3. The differences in data granularity between sector-specific and polymers-specific MFAs are accounted for by creating an additional polymer category named 'Unknown'. Since available sources are primary focused on sector-specific approaches, embedding polymer-specific data leads to data gaps compared to sector-specific overviews, that are explicitly and transparently captured within said 'Unknown' polymer category. This category includes plastic masses that are reported as aggregated in sector-specific data sources, rather than being detailed for their specific polymers' shares (therefore not allowing a specific classification at the level of polymers). Further, this category unveils hotspots and challenges in the combination of 'top-down' (i.e. from market sectors to specific products/value chain flows within those sectors) study with 'bottom-up' (i.e. from specific products/value chain flows to the related market sector) ones, allowing for a more comprehensive and reliable estimation (further details are provided in Annex 1.4).

The key sector-specific polymers insights were derived from Plastics Europe (2024) and Renewable carbon (2023). For all the sectors under scrutiny, the following fossil-based and bio-based polymers were modelled: low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), expanded polystyrene (EPS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyurethane (PUR), styrene-based polymers (acrylonitrile butadiene styrene (ABS)), poly(methyl methacrylate) (PMMA), polyamides (PA), polycarbonates (PC), bio-polypropylene (bio-PP), bio-polyurethane (bio-PUR), cellulose acetate (CA). An aggregated "other fossil-based" polymers category was created to include unspecified polymers and other plastics (e.g. other thermoplastics polymers not included by the previous list). Similarly, an aggregated "other bio-based" polymers category was also created to account other unspecified bio-based polymers (e.g. polylactic acid (PLA), polyhydroxyalkanoates (PHA)). The 'other-fossil-based' category account for approximately 11% of total fossil-based polymers production, including polymers with relatively lower market share, such as polyoxymethylene (POM) and polyethersulfone (PES; Plastics Europe, 2024). By contrast, "other bio-based" category includes all bio-based polymers, except for the three predominant bio-based polymers in the EU market (i.e., namely CA, bio-PUR and bio-PP, which collectively account for 51% of the bio-based market share; Renewable carbon, 2023). A full description of the assumptions employed in the polymers modelling is provided in Annex 1.4.

Following the same approach presented in Section 2.4.1, polymer-specific MFAs were generated applying the polymer-specific TCs to determine node-specific inflows and outflows. The polymer-specific MFAs is aligned with the system boundaries illustrated in Figure 1.

Figure 2. Overview of the top-down approach for building the polymers-specific MFAs within a sector.



Source: JRC elaboration. Note: TC = Transfer coefficient; MFA = Material Flow Analysis.

2.4.3 Product-specific modelling

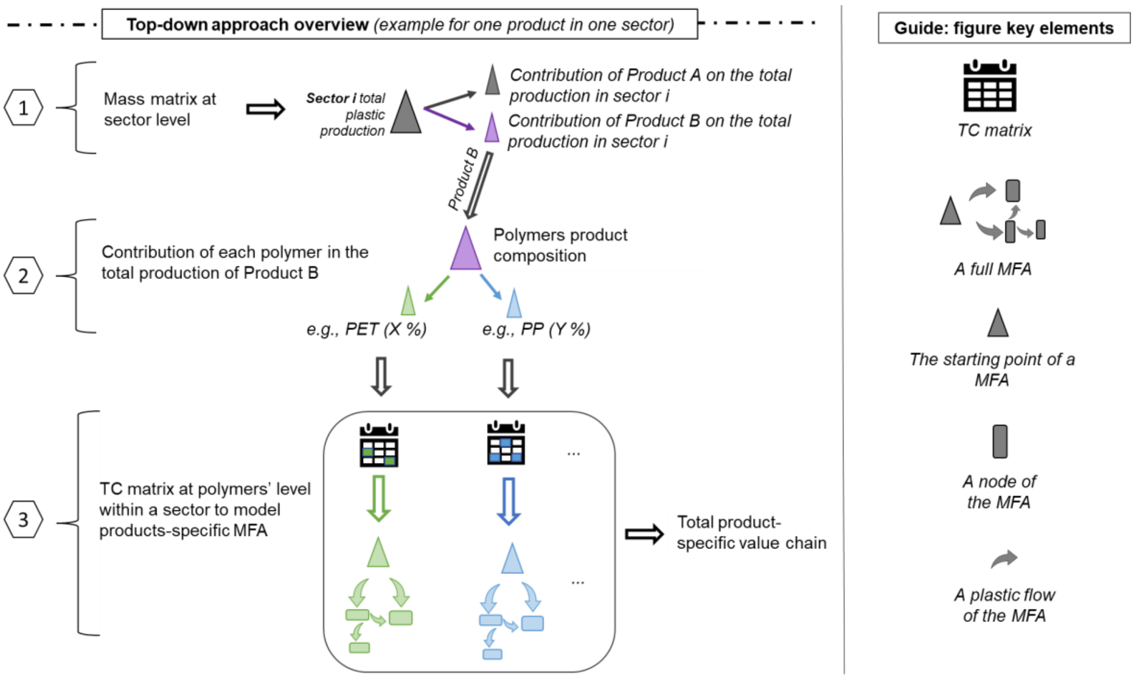
The sector-specific and polymers-specific information described in Section 2.4.1 and Section 2.4.2 enabled the mapping of product-specific flows.

To establish product-specific MFAs, the following steps were employed (Figure 3):

1. For the identified plastic products, insights and data from literature and relevant sources were gathered. This step was essential to collect information and to find for which products the product-specific MFA could be an added value;
2. To each product, its weight and bill-of-material were mapped. The information related to the product-specific weight enabled to prove its relevance when compared with the related total sector-specific production volumes. The bill-of-materials of each product stands for a detailed overview of its material-specific composition (especially key to derive the share of plastics – and related polymers – out of the total products weight);
3. A product-specific MFA was derived employing polymers-specific details when available and using polymers-specific TCs matrixes (Section 2.4.2) for the sector associated to the scrutinized product.

In the present report, this novel product-specific approach offers a flexible and replicable methodology, that could potentially also be applied to other product-specific MFAs even beyond plastics.

Figure 3. Overview of the top-down approach for building the product material flow analysis (MFAs).



Source: JRC elaboration. Note: TC = Transfer coefficient; MFA = Material Flow Analysis.

In the present study, the product-specific analysis was performed for flat screen and PET bottles, following the methodological details provided in Annex 3.3. Section 3.3 includes the findings for flat screen, whilst those related to PET bottles are provided in Annex 3.3. These products were selected as examples of the application of the developed methodology in the case of two different sectors.

2.5 Life Cycle Assessment overview

The LCA method is increasingly used as a tool for evaluating the environmental impacts of products. As defined by the International Organization for Standardization (ISO) in the specific standards (ISO 14040, 2006; ISO 14044, 2006). LCA evaluates the potential environmental impacts of a product throughout its entire life cycle. This study, employed LCA methodology to evaluate the environmental effects, following the guidelines set in the European Product Environmental Footprint (PEF) framework, as outlined in the Commission's Recommendation (EC, 2021). Specifically, the Environmental Footprint (EF) 3.1 method employs Life Cycle Impact Assessment (LCIA) techniques to derive results in a set of 16 impact categories starting from specific emission inventories. A thorough LCA analysis of the plastic value chain could be essential for achieving circularity and sustainability targets in the EU plastic industry. It finds critical areas contributing to environmental issues, enabling targeted interventions and greater transparency.

2.5.1 Goal and scope and functional unit

The specific aim of the analysis is to provide a comprehensive understanding of the environmental impacts associated to all plastic flows in the EU-27 value chain, providing a 'snapshot' for the year 2022 across multiple impact categories. For each sector under examination, the selected functional unit (ISO 14040, 2006; ISO 14044, 2006) focuses on the complete life cycle of plastic consumed within the EU-27 plastics value chain. Particularly, this analysis encompassed production, consumption, end-of-life management, mismanagement, losses, and trade, based on 2022 data. The functional unit is designed to avoid double counting concerning life cycle impacts' accounting related to plastic consumption, especially if the methodology developed in the present study would be applied to other non-EU countries. Such modelling approach especially influences plastic trade: impacts related to imports are captured in the present analysis (as imports are driven by the EU consumption needs), whilst impacts related to export are not captured (as these are driven by other geographies consumptions).

2.5.2 System boundaries

The system boundary of the LCA analysis reflects as much as possible the plastic value chain of the sectors under examination, adhering to the information retrieved from sector- and polymers-MFAs (Section 2.4.1 and 2.4.2). To ensure consistency and comparability across sectors, a standardized system boundaries' structure was applied, maintaining the same boundaries among the various sectors, likewise to the MFA analysis. However, a discrepancy between the MFA and LCA system boundaries was unavoidable due to the lack of standardized methodology and the high uncertainty associated to the modelling of impacts related to certain specific flows. Consequently, the LCA system boundaries excluded the following:

- Bio-based polymers: life cycle impacts related to bio-based polymers were excluded from the present study, due to the complexity of mapping plastic biopolymers' specific emission throughout their life cycles from production and especially end of life management. Similarly, life cycle impacts related to compostable plastic waste were excluded to the high uncertainty related to available statistics concerning plastics-specific flows entering composting facilities in the EU and the lack of plastic-specific associated dataset (it is worth noting that the current share of bio-based polymers production in the EU-27 did not surpass 1.0 % of the total plastic production (Plastics Europe, 2024) and that compostable plastic waste did not surpass 0.5% of the total waste generated in the EU-27 according to the findings of the present study, based on the approach described in the Annex 1.3);
- Plastic losses: life cycle impacts related to plastic losses in the environment were not accounted due to the lack of a standardized/recognized methodology to assess the impacts

associated to plastic lost in the environment, especially tracking not only the impacts in the water environmental sink but especially also on the soil environmental sink;

- Chemical recycling: life cycle impacts related to chemical recycling activities were excluded due to the lack of specific ecoinvent datasets to account for polymers-specific chemical recycling activities (it is worth noting that the waste of recyclable plastics entering chemical recycling facilities did not surpass 2.3% of the total waste sent to recycling in the EU-27, according to the findings of the present study, based on the approach described in the Annex 1.3).

The specific system boundaries selected for the present LCA analysis do not require an allocation of impacts/savings of plastics recycling across all the life cycle stages of the entire supply chain, as all plastic products in the EU economy are included within said boundaries. The present study also assumed the absence of value chains in which non-plastics products are substituted with recycled plastics (e.g., substitution of non-plastic products/components with ones made from recycled plastics). About the energy recovery during the plastic incineration life cycle stage, a system expansion approach was selected to capture the impacts/savings due to the avoided production of electricity and heat.

2.5.3 Life cycle inventories

To model the life cycle emissions of each step, data was retrieved from the 'Cut-off' ecoinvent datasets (ecoinvent, 2024, version 3.6) and processed using SimaPro (version 9.5.0.2, SimaPro 2024), based on the system boundaries defined in Section 2.4.1. ecoinvent datasets were carefully selected to accurately represent the technologies used in each life cycle stage, with a preference for the 'RER' (i.e. European) geography to best match the EU context. By contrast, for processes occurring outside the EU-27 (e.g. import of primary plastic produced abroad) the country-specific dataset was selected if available, otherwise, dataset based on the global (i.e. ‘RoW’ or ‘GLO’, namely rest-of-the-world and global) geography were used. As anticipated in Section 2.5.2, due to the absence of a standardized approach for assessing the environmental impacts of losses at different life cycle stages, these impacts were not included in the results presented in Section 3.4. The production of plastics outside the EU was modelled using ecoinvent datasets, specifically adapted to specific non-EU countries. Following the system boundaries and functional unit, the environmental impacts of exporting plastic polymers and products were not included in the analysis. In the LCA calculations, the entirety of the mass entering a given node (based on the sector-specific findings) was accounted and multiplied by its specific impacts for each life cycle under scrutiny (additional details are provided in Annex 2.2.

The input data description and the full list of datasets employed in the modelling are provided in the Annex 2.1 and Annex 2.2.

2.5.4 Life cycle impact assessment (LCIA)

The LCIA for each sector was performed using the EF method, version 3.1 (EF3.1), which is the latest recommended approach by the European Commission (EC, 2021; EC, 2013). Further, the latest guidelines provided by Andreasi-Bassi et al. (2023) were also considered when applying the method. This method evaluates 16 impact categories, including but not limited to Climate Change impact category.

3 Results

This Section outlines the key findings of the 2022 EU-27 plastics MFA. Key results are discussed in (i) Section 3.1 specifically for the analysis of sectors; (ii) Section 3.2 specifically for the analysis of polymers; and (iii) Section 3.3 specifically for the analysis of products. Additionally, Section 3.4 provides an overview of the Life Cycle Assessment (LCA) results.

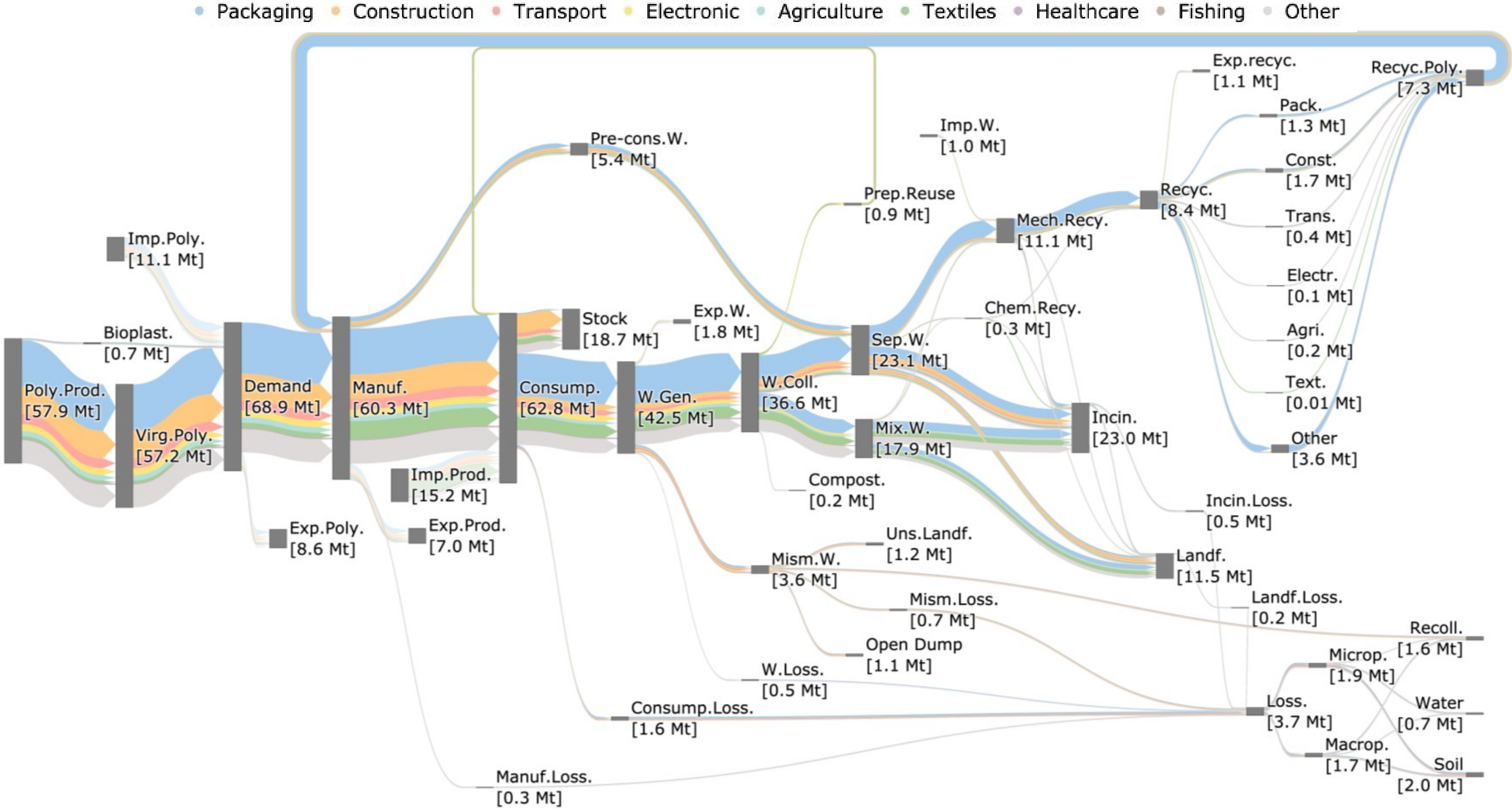
3.1 Sector specific results

This section provides an overview of the results of the sector-specific MFA for the whole 2022 EU-27. Results of the material flows along the whole EU plastic economy, detailed for each of the sectors under scrutiny, are illustrated in the Figure 4 Sankey diagram.

Results provided in Figure 4 are thoroughly described in a series of sub-sections, offering insights on the most important life cycle stages of the plastic value chain:

1. Plastic production, manufacturing, and consumption are presented in Section 3.1.1, including trade of primary plastics and plastic products;
2. Management of plastic waste is presented in Section 3.1.2, including trade of plastic waste, waste collection and processing through recycling, incineration and landfill;
3. Waste mismanagement and plastic losses are presented in Section 3.1.3.

Figure 4. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of sectors. Note: all data are expressed in Mt [Megatonnes] and refer to the year 2022. For each node (grey vertical rectangle) the label refers to the total input flows.



Source: JRC elaboration. Note: Virg.Poly.: Virgin polymers; Bioplast.: Bioplastics; Manuf.: Manufacturing; Poly.Prod.: Polymers production; Pre-cons.W.: Pre-consumer waste; Microp.: Microplastics; Macrop.: Macroplastics; Consump.: Consumption; W.Coll.: Waste collected; Prep.Reuse: Prep. To Reuse and Reuse; W.Gen.: Waste generated; Mism.W.: Mismanaged Waste; Mix.W.: Mixed waste; Sep.W.: Separated waste; Mech.Recy.: Mechanical Recycling; Chem.Recy.: Chemical Recycling; Recyc.: Recyclates; Incin.: Incineration; Landf.: Landfill; Recoll.: Recollected; Uns.Landf.: Unsanitary Landfill; Recyc.Poly.: Recycled polymers; Imp.Poly.: Import primary; Imp.Prod.: Import Products; Manuf.Loss.: Losses manufacturing; Consump.Loss.: Losses consumption; Imp.W.: Import waste; W.Loss.: Losses waste; Mism.Loss.: Losses mismanaged; Incin.Loss.: Losses Incineration; Landf.Loss.: Losses Landfill; Exp.Poly.: Export primary; Exp.Prod.: Export Products; Exp.W.: Export waste.

3.1.1 Plastic production, manufacturing and consumption

Results showed that in the MFA 2022, the total EU plastic **domestic production** amounted to 57.9 Mt, mostly due to fossil-based polymers as only 0.7 Mt of the total production could be attributed to bio-based polymers. In fact, despite a growing trend in the share of **bio-based plastic** in the EU has been seen in recent years (European Bioplastics, 2024), the overall volumes of such plastics were still negligible in 2022. Nonetheless, results suggested that bio-based polymers are especially common in the Packaging sector, cumulatively accounting to more than 57.5% of the total bio-based production (followed by the Textiles and Transport sectors, contributing to 15.1% and 12.2% of the total production, respectively). Other minor amounts of bio-based polymers can be associated to the production of the Construction and Electronics sector, while Agriculture, Fishing and Healthcare sectors were entirely driven by fossil-based polymers instead. Despite potential applications of bioplastics in the Agriculture sector have been acknowledged during the development of the present study, the lack of specific numerical data to map these flows hindered their inclusion in the MFA 2022. For instance, European Bioplastics (2024) indicated the use of bio-plastics in Agriculture (e.g. for mulching films) despite not providing numerical data to allow for polymers-specific granular overviews. To improve analysis of the sector-specific application of bio-plastics in the EU, future studies could focus on investigating such allocation especially starting via an assessment of bio-based polymers in the Agriculture sector.

Out of the total plastic produced (57.9 Mt), results in the MFA 2022 revealed the significant contribution of certain specific sectors: Packaging (37.9%) and Construction (22.3%), followed by Transport (8.1%). Once produced, plastics moves to manufacturing industries that convert polymers into plastic products.

During the production and manufacturing stages, a certain quantity of **'pre-consumer' waste** can be generated. This flow refers to plastic waste/residues being discarded during production and manufacturing activities. The flow of 'pre-consumer' waste differs from 'post-consumer' waste, that refers instead to the waste stream being generated after consumption. The present study employed a specific approach to estimate the quantity of yearly pre-consumer waste being generated (which relies on end-of-life statistics to deduct pre-consumer waste volumes; Annex 1.3). This novel approach was necessary due to the lack of available data and statistics concerning pre-consumer waste stream occurring at the production/manufacturing stage. The challenges associated with the mapping and data availability of pre-consumer was also recognized directly from stakeholders through feedback on the topic collected during the consultations (Section 2.2). Results in the MFA 2022 showed that pre-consumer waste accounted to around 9% of the total plastic being manufactured (60.3 Mt). It was then assumed that the flow of pre-consumer is managed as separately collected waste fraction, according to the approach described in Section 3.1.2.

In the MFA 2022, the total **plastic consumption** amounted to 62.8 Mt (Figure 4). Notably, this figure exceeded the total quantity of plastics manufactured, due to a significant influx of imports of products (which were modelled separately in this study from imports of polymers) to fulfil the EU plastic market needs. The substantial increase of plastic production can be especially attributed to the considerable imports of polymers and products for certain sectors, particularly Textiles (8.5 Mt; contributing to around 32.4% of the total 26.3 Mt of polymers and products being imported each year) and Packaging (6.6 Mt). Especially in the case of Textiles, the imports of products exceeded their relative domestic production (7.0 Mt mainly from China, Turkey and Republic of Korea; Manshoven et al., 2021), highlighting the EU dependence on external supplies for this sector.

A thorough analysis of plastic consumption contributions revealed that up to 67.7% of the consumed plastics were discarded as waste in the same year, whilst 29.8% were kept in stock, and a relatively small proportion of 2.5% were lost during use. Despite the significant influx of imported plastics products for the Textiles sector, the Packaging sector remains the major contributor to the consumption of products, accounting for 33.9% of the total plastic consumption (a 4 percentage points decrease compared to its relevance when zooming in the production life cycle stage).

The findings of the analysis underlined how the 'trade balance' (i.e. the difference between imports and exports) could vary significantly depending on the scrutinized sector. In the MFA 2022, the EU manifested **a surplus of imports over exports** of 10.7 Mt (specifically 2.5 Mt for polymers and 8.2 Mt for plastic products). As previously mentioned, this import surplus was driven by Textiles (1.1 Mt import surplus), but also by Packaging (1.8 Mt import surplus). Similarly, import surplus for plastic products was driven by Textiles (6.3 Mt import surplus) and Transport (0.7 Mt import surplus). Despite this, certain sectors manifested an export surplus for polymers and plastic products (i.e. 0.2 Mt for Agriculture and 0.01 Mt for Fishing). Data available to model the import flows (both polymers and products) lacked specific details concerning the potential share of bio-based and recyclates in the traded flows. Consequently, such details were not included in the present study. Notably, the importance of refinements in this aspect has been recognized as a key future goal for analysis devoted to unveiling flows of the EU plastic value chain by several stakeholders during the consultation.

Out of the total plastic consumption, around 18.7 Mt were kept in **stock** in the MFA 2022. In the context of the present study, the stock life cycle stage is interpreted as a yearly 'stock variation', since it was calculated as the difference between consumption and waste data for each sector (Section 2.4). Such 'stock variation' presented differences among sectors, depending on the sector-specific specific products' lifespan and purposes. In the Packaging sector, many plastic products were immediately discarded after use, therefore resulting in a relatively low stock variation of only 2.7% of the total sector consumption (21.3 Mt). This low stock variation could be attributable to the very short lifetime of packaging products, typically less than a year. Similarly, the typical short-lived/mono-use nature of Healthcare products resulted in no stock being accumulated, also following high supplies' turnovers. On the other hand, sectors characterized by longer products' lifespans, such as Construction, Textiles, and Transport, contributed significantly to the total stock variation. The Construction sector, resulted in the largest share accounting for 45.8% of the total stock, due to the long lifespan of buildings and related infrastructures. The Textiles and Transport sectors also contributed substantially, accounting for 12.8% and 10.4%, respectively. Despite out of the scope of the present study, employing dynamic material flow analysis models to account for specific products lifespans (via e.g. statistical distribution such as exponential, Weibull or Normal/Log-Normal distributions) could prove to be key to shed light on the dynamics of plastic waste, stock and reused of plastic products.

3.1.2 Plastic waste

In the MFA 2022, EU consumers generated a total of 42.5 Mt of **post-consumer plastic waste**. Most of the waste generated derived from Packaging and Textiles, which accounted for 19.7 Mt and 6.2 Mt of the total waste volumes, respectively. Despite the Textiles sector represented solely around 2.7% of the total production volumes, its contribution increased more than four times (14.5% of the total plastic waste generation), consequently to the significant imports of products occurring in this sector (Section 3.1.1).

Out of the total waste generation (42.5 Mt), a share equal to 4.2% was **exported** outside the EU (1.8 Mt), with Textiles being the prime responsible of such flow (export of synthetic textiles mainly to Turkey, US, Morocco and China; Manshoven et al., 2021). Textiles contributed alone up to 0.6 Mt of the total exported volumes, followed by Packaging (0.5 Mt) and Construction (0.3 Mt). Notably, the Textiles and Construction sectors exported respectively 10.4% and 12.0% of their total waste volumes (equal to 6.2 Mt for Textiles and 2.8 Mt for Construction). The export of waste from these sectors could be mainly driven by economic reasons. For instance, in the case of Textiles, the demand from extra-EU countries drives exports trends, mostly for reuse and recycling activities (as stated by

Lingas et al., 2023). However, the same study suggested that part of such waste may be inadequately managed instead, due to the not-established waste collection systems and treatment technologies in the recipient countries (e.g. Asian and Africans countries; Lingas et al., 2023).

In the MFA 2022, most of the waste generated was properly collected (36.6 Mt) either as a separated (48.2%) or as a mixed stream (48.8%), while a smaller portion as waste prepared for reuse and reused (2.5%) or composted (0.5%). The **collected waste** was predominantly composed of packaging products, accounting to 48.3% of the total plastic waste collected. Due to the high volumes and relatively short lifespan of products (typically not exceeding one year), Packaging waste dominated collected waste flows. Around 17.7 Mt of Packaging waste were collected: of this quantity a significant portion was collected separately (62.9%), with the remaining being disposed as a mixed stream (36.6%). The remaining fraction was sent to composting (0.5%). By contrast, Textiles waste (5.5 Mt) were mostly collected as mixed waste (74.5%). The remaining fraction was either separately collected (11.8%) or prepared for reuse and reused (13.7%). These findings could be attributable to the disparity in the extent of collection infrastructures. Specifically, Textiles was characterized by a relatively limited and underdeveloped collection infrastructure, which limited an efficient separation and subsequent processing of textile waste (EC, 2023c). By contrast, the Packaging sector benefits from a more widespread collection and sorting system, enabling more effective waste management practices. For Construction, Transport and Healthcare, the generated waste was assumed to be instead entirely separately collected, as these sectors are subject to regulatory frameworks that are less dependent on the consumers' behaviour (Annex 1.3).

In the present study, the quantity of **separately collected waste** considered both pre-consumer (5.4 Mt; further details in Annex 1.3) and post-consumer quantities (17.7 Mt), totalling to 23.1 Mt. Of these total volumes, 41.7% were sent to recycling facilities, while the remaining fraction being incinerated (41.2%) or landfilled (17.1%). By contrast, waste **collected as a mixed fraction** (17.9 Mt) was primarily sent to incineration and landfill, covering 60.2% and 35.6% of the total volumes of this waste stream. Despite part of waste is being collected within the mixed fraction, a certain valuable portion is still sorted and deviated to recycling (4.3% of mixed waste) due to its intrinsic recyclability potential. By contrast, for the Construction, Transport, Textiles, Fishing and Healthcare sectors the mixed waste was entirely sent to incineration and landfill facilities, respectively for fractions covering 60% and 40% of their relative mixed waste volumes.

Out of the total waste collected, 0.2 Mt were sent to **composting** facilities within the EU territory. Packaging accounted for the largest fraction of this quantity covering 46.0% of this waste. The Transport sector followed Packaging and contributed to 21.6% of the same total volumes. Such results are largely attributable to the high share of bio-based polymers (such as cellulose acetate) in the production and manufacturing stages of these sectors, therefore contributing to the generation of compostable waste. This figure could particularly be influenced not only by specific consumers' behaviour in disposing compostable plastics, but also by waste sorting operations occurring along the waste management stages.

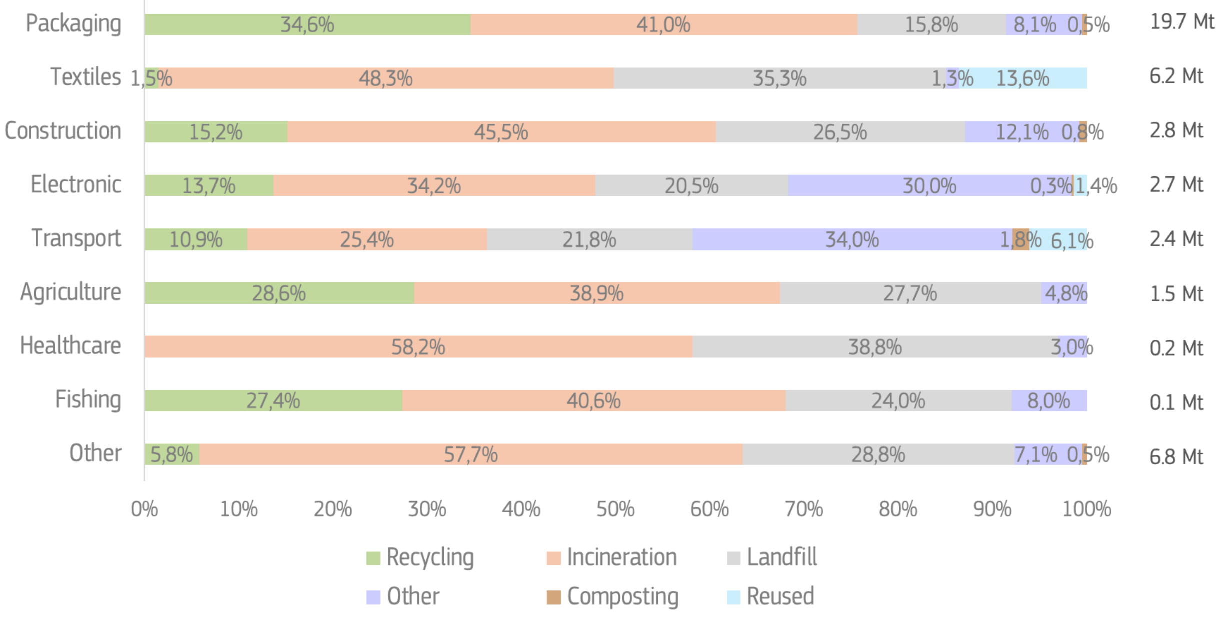
The **preparation for reuse and reuse** flow accounted to a total of 0.9 Mt for the whole value chain under scrutiny (i.e., Textiles, Electronic and Transport). Among the various assessed sectors, Textiles contributed to the largest volumes of waste prepared to be reused (0.8 Mt), followed by the Transport (0.1 Mt) and the Electronic (0.04 Mt) sectors. The high quality and durability of products in Textiles, Electronic and Transport sectors (e.g. synthetic fibres), and the presence of high-value components (e.g. precious metals in electronic devices), made them suitable for reuse. For instance, electronic products (such as laptops) being disposed but having residual value could be processed via e.g. data wiping and maintained for replacing worn-out parts with new ones, enabling them to be functional/marketable again.

In the MFA 2022, a total of 11.4 Mt (26.8% of the total waste generated) was sent to **recycling** facilities. Of this quantity, around 1.0 Mt of recyclable waste were imported. Despite the recent

development of alternative plastic recycling routes, most of the valuable plastics waste is still recycled via mechanical processes (97.7%, or 11.4 Mt), with only around 2.3% (or 0.3 Mt) being treated via chemical recycling instead.
The estimated recycling efficiency (i.e., share of plastic waste being recycled out of the total input to a recycling plant) from these technologies varied across sectors, ranging from 76.6% in the case of Packaging to 56.0% in the case of Transport. Lower efficiencies, such as those acknowledged for the Transport and Electronics sectors, are attributable to the higher complexity in the materials of products hindering recyclability (e.g. high presence of multi-polymers/multi-materials components). Notwithstanding the sector-specific recycling performances, residues from recycling activities were nonetheless generated and either sent to incineration and landfill (respectively 24.4% and 3.2% of the total waste sent to recycling).

Results of the present study underlined that **incineration** and **landfilling** still represent the dominant waste management options in the EU-27, accounting for 23.0 Mt of waste being incinerated and 11.5 Mt being landfilled yearly. However, there were notable variations in waste management practices across different sectors. Beyond Packaging, sectors significantly contributing to influx of plastic waste to incineration include Textiles and Construction, cumulatively contributing to 21.5% of the total waste entering to incineration facilities. The same sectors contributed instead to 29.1% of the total waste entering to landfill facilities. A comprehensive overview of sector-specific plastic waste management in the EU-27 is provided in Figure 5.

Figure 5. Rates [%] of total plastic sent to recycling, incineration, landfill, prepared to be reused or lost and mismanaged by each sector. The percentages are calculated based on the input amounts of the processes, and considering waste being generated and trade of waste. Possible rounding effects may be present in the data.



Source: JRC elaboration.

In this study, the overall **recycling rate** (i.e., estimated as the total quantity of recyclates produced out of the total waste generated), was estimated to be 19.6%, which decreases to 17.1% when exports are considered (Table 1). Packaging represented a key source of valuable plastic waste, which covered the 74.6% of the total recycling input (equal to 11.4 Mt). Non-negligible contributions were also noticeable for the Construction sector, contributing to 6.2% of the total recycling input. Notably, Packaging and Textiles sectors achieved recycling rates (pre-export) in the order of 33.1% and 1.5%, respectively.

Table 1. Recycling rates [%] pre-export for the sectors under scrutiny. The rates were estimated as the total quantity of recyclates produced out of the total sector-specific post-consumer waste generated.

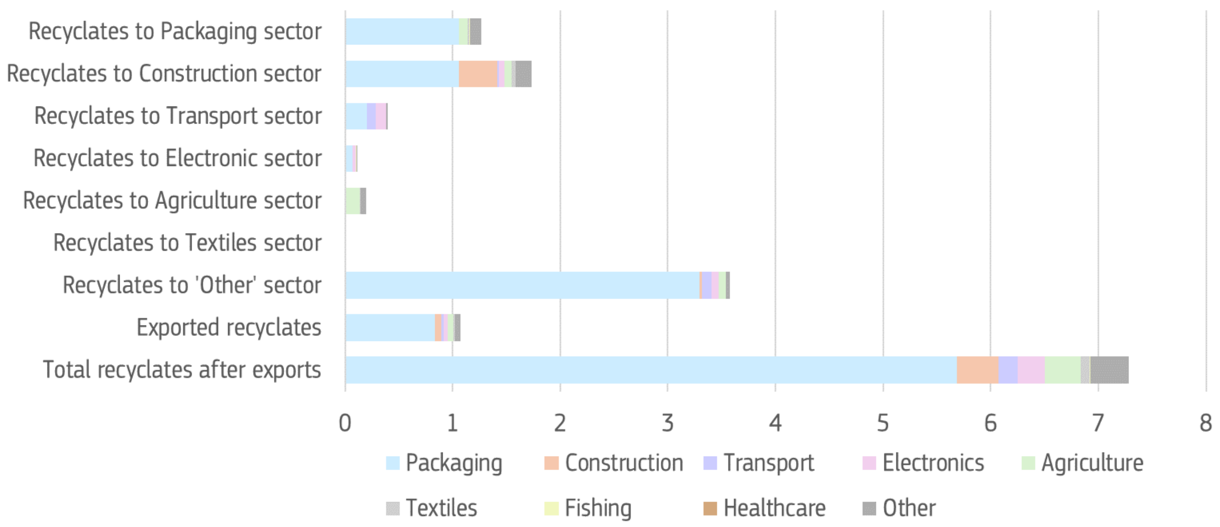
MFA steps	P	C	T	E	A	TEX	H	F	O	All sectors
Recycling rate [%]	33.1%	15.8%	8.4%	10.4%	25.3%	1.5%	0.0%	16.2%	5.9%	19.6%
Total [Mt]	6.5	0.5	0.2	0.3	0.4	0.1	0.0	0.01	0.4	8.4

Source: JRC elaboration. Note: P = Packaging; C = Construction, T = Transport, E = Electronic, A = Agriculture, TEX = Textiles, H = Healthcare, F = Fishing, O = Other.

The total recyclates generated in the MFA 2022 by the EU-27 value chain amounted to 8.4 Mt, of which 1.1 Mt were exported (87.2% of recycled plastics were manufacturing within the EU-27; (Plastics Europe, 2024).

The present study acknowledged a lack of literature information concerning the potential **fate of recycled plastics** (i.e., the sector in which recycled plastics are employed to manufacture new plastic products). Nonetheless, this study tackled this challenge by mapping fates through data from few specific data sources allowing the mapping of these flows specific sectors (such as Souder et al., 2024 and Watkins et al., 2020). The list of sectors for which such granular detail was achievable is illustrated in Figure 6. Notwithstanding this effort, the fate of a certain quantity of recycled plastic (equal to 3.5 Mt) remained uncertain/unknown (mapped under the '*Recyclates to 'Other' sector*' label in Figure 6), and it was mapped as suggested by Plastics Europe (2024). Overall, results indicate that most of the recycled plastics were employed to manufacture new products in the Construction (1.7 Mt) sector, followed by the Packaging sector (1.3 Mt). On top of Figure 6, a detailed overview of the fate of recyclates in the EU-27 can also be found in Annex 3.

Figure 6. Plastic flows of each economic sector related to recycling and recycled plastic fate in EU-27 for the reference year 2022. All data are expressed in Mt [Megatonnes].



Source: JRC elaboration. Note: Recyclates to 'Other' sector = label referring to recycled plastics having an uncertain/unknown fate.

Mapping the fate of recycled plastics represent a potential indicator for circularity, as it could be used to calculate the ratio between the quantity of recycled plastics destined to a specific sector out of the total manufacturing volumes in that sector. For instance, results underlined that for the Construction and Packaging sectors (the two rectors receiving most of recycled plastics; Figure 6), this ratio would be equal to 14.3% and 6.6%, respectively. Notably, despite receiving lower quantities of recyclates, this ratio could be significant also for sectors such as Transport (9.3%) manifesting as well lower manufacturing volumes compared to Construction and Packaging.

3.1.3 Plastic losses and mismanagement waste

In the MFA 2022, a total of 3.7 Mt of plastics was lost in the EU-27. Overall, comparable microplastics and macroplastics quantities were lost (1.9 Mt and 1.7 Mt, respectively, either in soil or water). A detailed overview of the key findings concerning losses occurring at the various life cycle stages scrutinized in the present study is provided hereafter (further details on the various losses flows coupled with examples are provided in Annex 1.3):

- **Manufacturing losses**: these losses were estimated to be equal to 0.3 Mt, accounting for 0.4% of the total EU plastic manufacturing. Notably, manufacturing losses contributed to 7.0% of the total losses, of which the Packaging and the 'Other' sectors (primarily losses of paints) sectors contributed significantly, resulting respectively in 0.02 Mt and 0.2 Mt. These results were derived considering the suggestions from the 2019 MFA (Amadei and Ardente, 2022) and the Staff Working Document (SWD) for the EC Regulation on microplastics pollution (EC, 2023b). The losses during this life cycle stage covered microplastics releases, that could occur during the production, transportation, storage and processing of raw materials. Interestingly, most of these losses were dispersed in soil and water (respectively 43.6% and 43.4%), while a smaller portion was recollected (13%).

- **Consumption losses:** during this stage, losses were estimated to be equal to 1.6 Mt, accounting for 2.5% of the total EU plastic consumption. Notably, consumption losses dominated the plastic value chain, contributing to 43.1% of the total losses. The Transport sector was a significant contributor to this flow, with an estimated 0. 5Mt of losses, primarily due to tyre abrasions occurring during transportation. In contrast, the Textiles sector accounted for relatively minor losses of 0.02 Mt, mainly resulting from the washing of synthetic textiles. As for the earlier life cycle stage, these results used insights from the 2019 MFA (Amadei and Ardente, 2022), Kounina et al. (2024) and the Commission SWD on microplastics pollution (EC, 2023b). The Packaging sector also played a substantial role in these losses, with 1.0 Mt of plastic waste generated, largely due to littering events involving packaging products, such as the cracking of plastic bags. Interestingly, an equal quantity of microplastics and macroplastics were generated during this stage (further details are provided in Annex 1.3).

- **Waste losses:** during this stage, losses occurred due to unintentional events related to waste management and handling inefficiencies, resulting to 0.5 Mt of losses. This stands for 1.1% of the total EU waste generated and accounts for 12.4% of the total losses. Notably, the Packaging sector was the primary contributor to these losses, with an estimated 0.4 Mt, while the 'Other' sector accounted for a smaller share of 0.1 Mt. As for the earlier life cycle stage, these results used insights from the 2019 MFA (Amadei and Ardente, 2022) and the Commission SWD on microplastics pollution (EC, 2023b).

- **Mismanaged losses:** a considerable proportion of total losses, equal to 20.0% (0.7 Mt), occurred as a result of mismanaged waste that ultimately ended up in the environment. Notably, mismanaged losses accounted for a substantial 42.3% of the total macroplastics, highlighting the importance of proper waste management in preventing environmental pollution. The majority of these macroplastics were lost due to inadequate management practices, which ultimately resulted in mismanaged waste being released into the environment.

- **Incineration and landfill losses:** plastic losses occurring during the incineration and landfill stages were estimated to be equal to 0.7 Mt. This total included 0.5 Mt of plastic waste sent to incineration, which accounts for 2.0% of the total waste incinerated, and 0.2 Mt sent to landfill, being 1.6% of the total waste landfilled. Notably, the plastic losses from incineration and landfill cover 12.5% and 5.0% of the total losses. To calculate plastic losses in this life cycle stage was followed the same approach proposed by the 2019 MFA (i.e. insights from a 2019 European Chemical Agency report; ECHA, 2019).

According to the findings of the present study, plastic losses to the soil environmental compartment stood for a significant sink, with around 2.0 Mt (54.8% of total losses) most of which generated during the consumption stage. By contrast, only a minor portion of losses was collected in the water compartment (0.7 Mt), of which most of the losses originated from the incineration treatment. An overview of the total losses per sector and per environmental compartment of the final release (including any potential recollection) is reported in Table 2.

Table 2. Sector-specific releases [ktonne] of plastics (sum of all releases along the value chain) per sector and per environmental compartment or potential recollection routes.

MFA steps	P	C	T	E	A	TEX	F	H	O	Total [kt]
Mac. to water	99.8	12.1	24.3	25.1	2.8	4.1	6.2	0.4	15.7	190.5
Mac. to soil	394.3	54.7	87.2	90.0	20.2	14.6	1.8	4.1	52.2	719.0
Mac. recollected	635.2	67.2	43.6	45.0	14.4	0.0	0.0	7.7	22.7	835.8
Mic. to water	138.4	33.0	91.2	18.5	13.1	58.9	0.6	2.2	168.1	523.9
Mic. to soil	651.5	45.2	341.2	20.1	15.2	67.0	0.7	2.3	128.3	1271.4
Mic. recollected	3.3	2.0	57.8	0.4	1.7	0.5	0.0	0.0	27.3	93.1

Source: JRC elaboration. Note: P = Packaging; C = Construction, T = Transport, E = Electronic, A = Agriculture, TEX = Textiles, H = Healthcare, F = Fishing, O = Other; Mic = microplastics; Mac = macroplastics.

The mismanagement of plastic waste played a crucial role in the overall EU-27 plastic value chain, being a significant fraction (8.6%) of the potential fates of the total waste generated. Around 3.2% of the mismanaged waste was lost in water, 11.5% in soil and a fraction equal to 5.5% recollected (as suggested by Peano et al. (2020) due to activities such as collection losses by waste pickers).

The 2022 study from Systemiq (Systemiq, 2022) enabled the estimation of the potential fate related to the mismanaged waste. Notwithstanding the fraction that is recollected, results suggested that 39.3% of mismanaged waste could be ultimately disposed of in unsanitary landfills, 35.7% in open dump sites and 25.0% ultimately lost in the environment. The flow of mismanaged waste was particularly significant for the Packaging (1.2 Mt), Transport (0.8 Mt) and Electronic (0.8 Mt) sectors (cumulatively covering 76.0% of the total mismanaged waste stream). Mismanaged waste estimations (derived from Peano, 2020 and Kaza et al., 2018) also captured the quantity of Packaging waste that could be uncollected/unaccounted or inappropriately disposed/managed. Such estimate reflects the findings from the World Bank (2018) suggesting that part of waste could not only be uncollected (i.e., independently managed by households and ultimately e.g. dumped or burned) but also unaccounted (i.e. waste generated with “missing”/unknown fate). Transport and Electronic represented other relevant sectors contributing to the total mismanaged waste stream, likely due to the high value of materials/components of products in these sectors (such as vehicles and laptops) contributing to irregular waste flows.

3.2 Polymers specific highlights

This section presents an overview of the key findings related to the polymer-specific analysis (developed adopting the top-down approach outlined in Section 2.4.2 and detailed in Annex 1.4). Such overviews target the relevant life cycle stages for a set of specific polymers outlined in Section 2.4.2 and illustrated in Figure 7 (i.e., LDPE, HDPE, PP, PS, EPS, PVC, PET, PUR, ABS, PMMA, PA, PC, bio-PP, bio-PUR, CA).

- **Production:** PP (10.8 Mt), LDPE (9.5 Mt) and HDPE (7.2 Mt), represented the most produced polymers in the EU accounting for 47.5% of the total production. These polymers were mainly employed in the Packaging and Construction sectors, further confirming the importance of these sectors in the EU economy (Section 3.1). Among the polymers contributing to the total quantity of bio-based polymers produced in the MFA 2022, bio-PP and bio-PUR played a significant role (amounting to 0.1 Mt each), followed by 0.07 Mt in the case of CA. The remaining quantity of bio-based polymers produced in the EU (0.4 Mt) were grouped in the present study under the 'Other biopolymers' (0.3 Mt) and 'Unknown' category (0.1 Mt). The domestic production was supplemented by an import surplus (i.e., imports of polymer surpassing the related exports), to meet the EU market demand. PET and PP polymers were subjected to a significant trade activity. For such polymers results underlined imports equal to 2.7 Mt for PET and 1.5 Mt for PP, and exports respectively equal to 1.7 Mt and 0.8 Mt.

- **Manufacturing:** PP (10.5 Mt), LDPE (9.33 Mt), HDPE (6.5 Mt), PET (5.7 Mt), and PVC (4.5 Mt), represented the polymers mostly demanded by the EU manufacturing industry for the manufacturing of plastic products. Notably, those polymers accounted for 67.1% of the total plastic manufacturing. The manufacturing stage was characterized by an import surplus, driven by significant imports of PET (2.7 Mt) and PP (1.9 Mt), since these polymers play a key role in the Textiles sector, which dominates the imports of plastic products in the EU.

- **Consumption:** following the results associated with manufacturing, PP (10.1 Mt), LDPE (8.5 Mt) and PET (7.0 Mt) also played a significant role in the consumption life cycle stage (especially because of the significant consumption of Packaging products). Interestingly, results of the present study highlighted a significant gap of 9.5 Mt between the total plastic consumption retrieved from sector-specific MFAs and polymers-specific MFAs. Such gap was transparently mapped to an 'Unknown' category, as described in Section 2.4.2 which highlights the potential differences concerning a polymer-specific approach and a sector-specific one. When looking at the polymers-specific contribution to the 'stock variation', results highlighted the relevant role of the PVC (2.6 Mt), PP (2.3 Mt) and PUR (1.7 Mt) polymers. In fact, such polymers are largely employed in the Construction and Transport sectors, which significantly contribute to the total EU 'stock variation'.

- **Waste management:** The total waste generated in the EU amounted to 42.5 Mt, with PP (7.5 Mt) and LDPE (6.9 Mt) polymers being the primary contributors, due to their significant role in the plastic production. Notably, PP and LDPE polymers (respectively 6.5 Mt and 6.2 Mt of collected waste) were predominantly separately collected, especially due to their significant role in the Packaging sector waste. Additionally, PET ranked third in terms of waste generated (5.9 Mt): remarkably, out of the total waste generated quantity 5.3 Mt were collected. Although PET was mainly separately collected in the packaging sector, for other sectors such as Textiles its fraction collected as mixed waste was still relevant due to the sector-specific collection system (as a reference, 15% of PET produced was employed in

Textiles products). Additionally, also PUR, PA, PMMA were primarily collected as part of mixed waste, due to their significant contribution in the heterogeneous 'Other' sector.

- **Recycling:** The total waste sent to recycling amounted to 11.4 Mt in the MFA 2022, of which PET (1.9 Mt), HDPE (1.6 Mt) and LDPE (1.5 Mt) were the primary contributors. Additionally, an import of waste equal to 1.0 Mt was sent to mechanical recycling. As previously mentioned in Section 3.1.2, a portion equal to 4.2% of the total mixed waste was sent to recycling, of which PP (0.2 Mt) and LDPE (0.1 Mt) being the main contributors. By contrast, it is worth considering that the polymers PMMA, PC and 'Other fossil-based polymers' were not part of the waste sent to recycling due to lack of data (Annex 1.4). Out of the total waste sent to recycling, 8.4 Mt were converted into recyclates, which were used to manufacturing new plastic products in EU (7.3 Mt) or extra-EU (1.1 Mt). The primary recyclates polymers were PET (1.8 Mt), HDPE (1.6 Mt), LDPE (1.5 Mt) and PP (1.4 Mt), which were largely originated from Packaging. As detailed in Table 3, the recycling rate (i.e., estimated as the total quantity of recyclates produced out of the total waste generated) depends on the sector scrutinized.

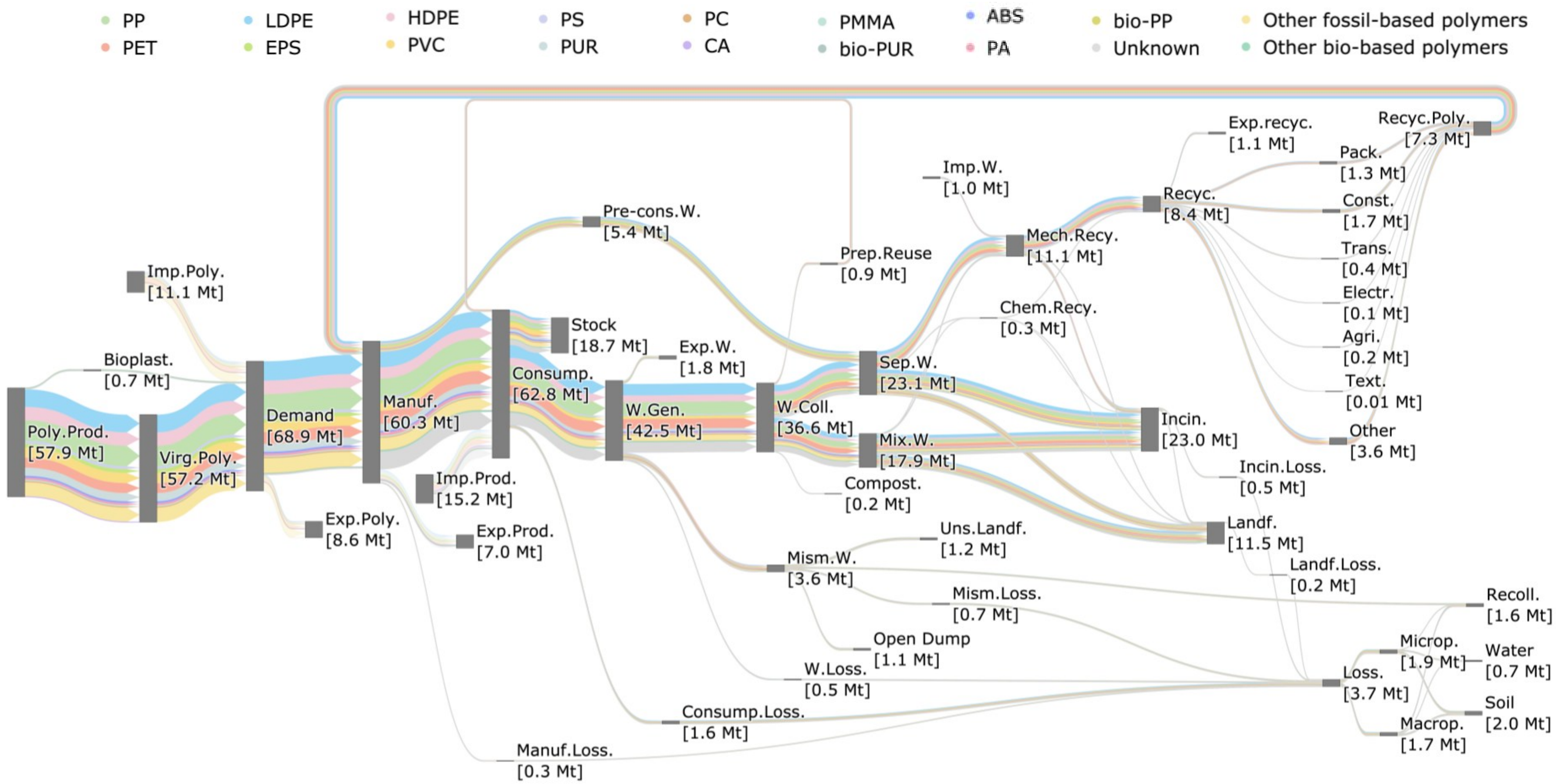
Table 3. Recycling rates [%] pre-export of the polymers under scrutiny. These rates were estimated as the total quantity of recyclates produced out of the polymer-specific total waste generated.

Sectors	PET	HDPE	LDPE	PP	PVC	PS	EPS	PUR	ABS
Packaging	46.8%	51.3%	25.4%	25.8%	38.0%	23.7%	23.9%	0.4%	-
Construction	-	16.7%	16.7%	16.7%	14.7%	16.7%	16.3%	0.0%	0.0%
Transport	-	0.7%	0.7%	17.3%	0.7%	0.7%	-	0.0%	0.0%
Electronic	0.7%	0.7%	0.7%	21.4%	0.7%	22.4%	-	0.7%	20.4%
Agriculture	-	28.3%	28.0%	23.0%	1.9%	-	-	-	-
Textiles	1.4%	-	-	0.2%	-	-	-	-	-
Fishing	9.7%	17.9%	17.4%	14.1%	-	-	-	-	14.6%
Healthcare	-	-	-	-	-	-	-	-	-
Other	4.0%	7.3%	7.1%	5.8%	5.5%	6.3%	6.8%	5.6%	6.0%
Total recyclates pre-export [Mt]	1.8	1.7	1.5	1.4	0.6	0.2	0.1	0.1	0.04

Source: JRC elaboration.

- **Incineration and landfill:** the total waste that was not recycled (totalling to 34.6 Mt) was ultimately sent to incineration and/or landfill. PP represented the main contributor to both incineration (4.4 Mt) and landfill (2.0 Mt). A polymer-specific analysis highlighted that EPS and PUR polymers were primarily sent to incineration (respectively 72.4% and 63.0% of their total waste generated). By contrast, the main fate of polymers waste such as 'Other fossil-based polymers' and PMMA was instead landfilling (respectively 37.9%, 36.7% of their total waste generated).

Figure 7. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers. All data are expressed in Mt [Megatonnes] and refer to the year 2022. For each node (grey vertical rectangle) the label refers to the total input flows.



Source: JRC elaboration. Note: nodes name are explained in Figure 4.

3.3 Products specific highlights

This section presents the key findings related to product-specific MFAs, especially an overview related to flat screen products (e.g. monitors and TV displays) was described below and illustrated in Figure 8. Furthermore, an additional methodological example related to PET bottle was reported in Annex 3.3.

An overview of the key findings concerning flat screens occurring at the various life cycle stages scrutinized in the present study is provided hereafter:

- **Production and manufacturing:** the total plastic demand for flat screens production amounted to 256.4kt, of which HDPE (3%), PP (1%), PVC (10%), PUR (4%), ABS (38%), PC (21%) and 'Other fossil-based polymers' (23%) were employed. Notably, the imports of polymers and plastic components were significantly for the manufacturing stage of new products, particularly the import of 'Other fossil-based polymers' (e.g. thermosets polymers).

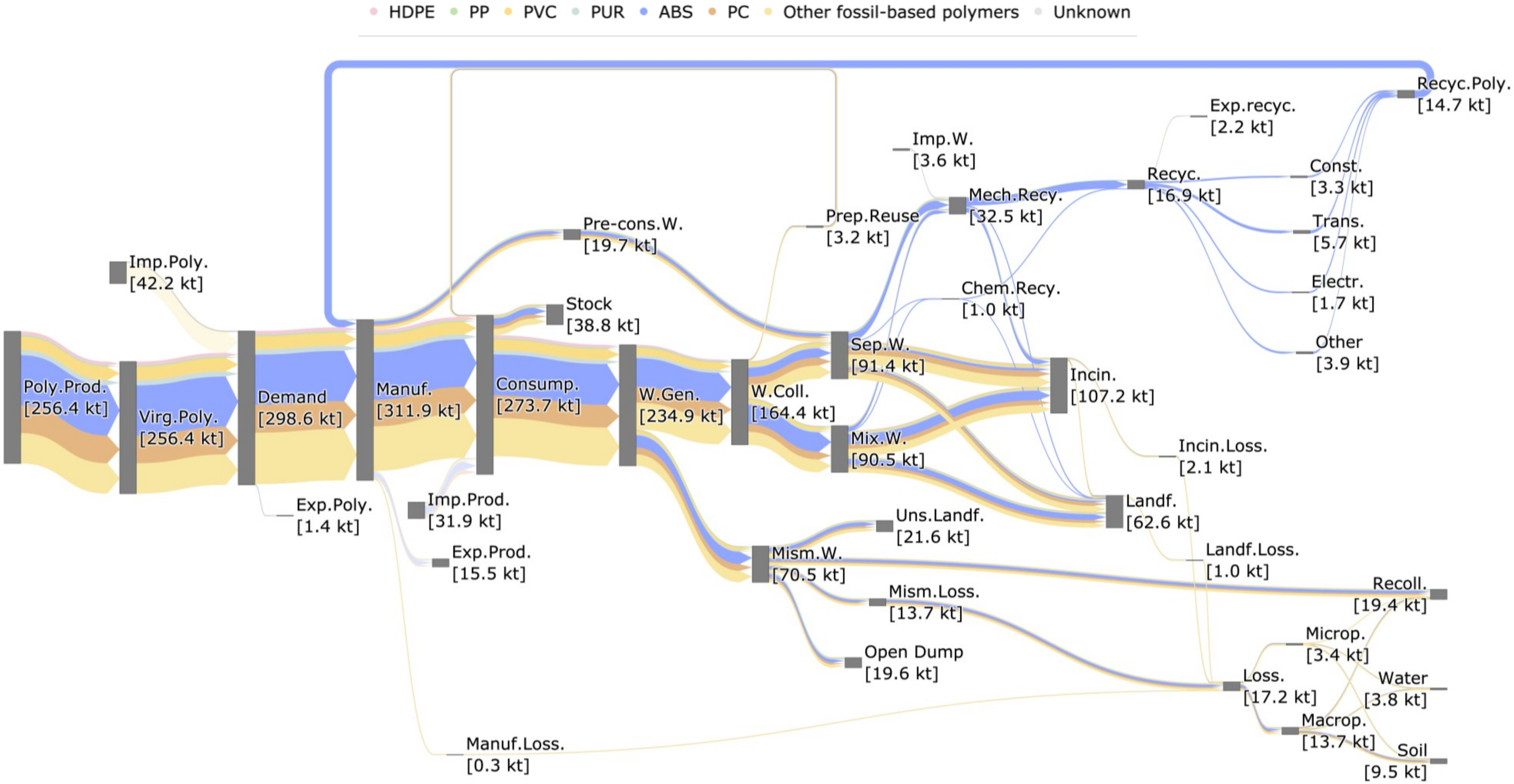
- **Consumption:** ABS and PC were the primary contributors to the polymer's consumption, accounting for 10.4% for total ABS consumption 0.9 Mt and 8.6% for total PC consumption 0.6 Mt in the EU-27. Additionally, the total consumption was also characterized by a 'stock variation' equal to 38.8 kt, which was calculated based on the TC (14.2%) for the Electronic sector.

- **Waste management:** following the approach outlined in Section 2.4.3, 70% of the total waste generated (164.4 kt) was collected, mainly as separated waste (91.4 kt), while a minor fraction as part of the mixed waste (90.5 kt). The remaining 30% of waste generated (70.5 kt) was mismanaged of which primary destinations were unsanitary landfill and open dump (respectively 30.7% and 27.9%), while 19.5% contributed to the overall plastic releases. However, efforts to reclaim mismanaged and losses waste enabled to recollect a portion equal to 19.4kt.

- **Recycling:** a total of 12.7% (29.9 kt) of waste generated was sent to recycling facilities, with ABS polymer being the predominant polymer (23.8 kt). Out of the total waste sent to recycling, 14.7 kt was converted into recyclates, which were employed to manufacturing new plastic products within Electronic and other sectors (e.g. Construction and Transport) in the EU. Notably, the product-specific recycling rate pre-export (i.e., recyclates produced over total waste being generated) was calculated equal to 7.2%, considering that in the Electronic sector 10.4% was the average recycling rate.

- **Incineration and landfill:** Despite most of the waste was separately collected, the incineration and landfill remained the primary disposal treatments. Notably, 40.5% of the total waste generated was sent to incineration, with ABS being the predominant polymer. In contrast, 24.3% of the total waste generated was sent to landfill, with 'Other fossil-based polymers' being the major contributor.

Figure 8. Sankey diagram of the material flow analysis of EU-27 plastic flows related to flat screens. All data are expressed in kt [Kilotonnes] and refer to the year 2022. For each node (grey vertical rectangle) the label refers to the total input flows. The simplified visualisation for the flows of recyclates to manufacturing is intended to account solely for the recyclates used within the displayed sector. All other recylates are intended to be employed in the manufacturing of each specific sector of destination (according to their 'fate').

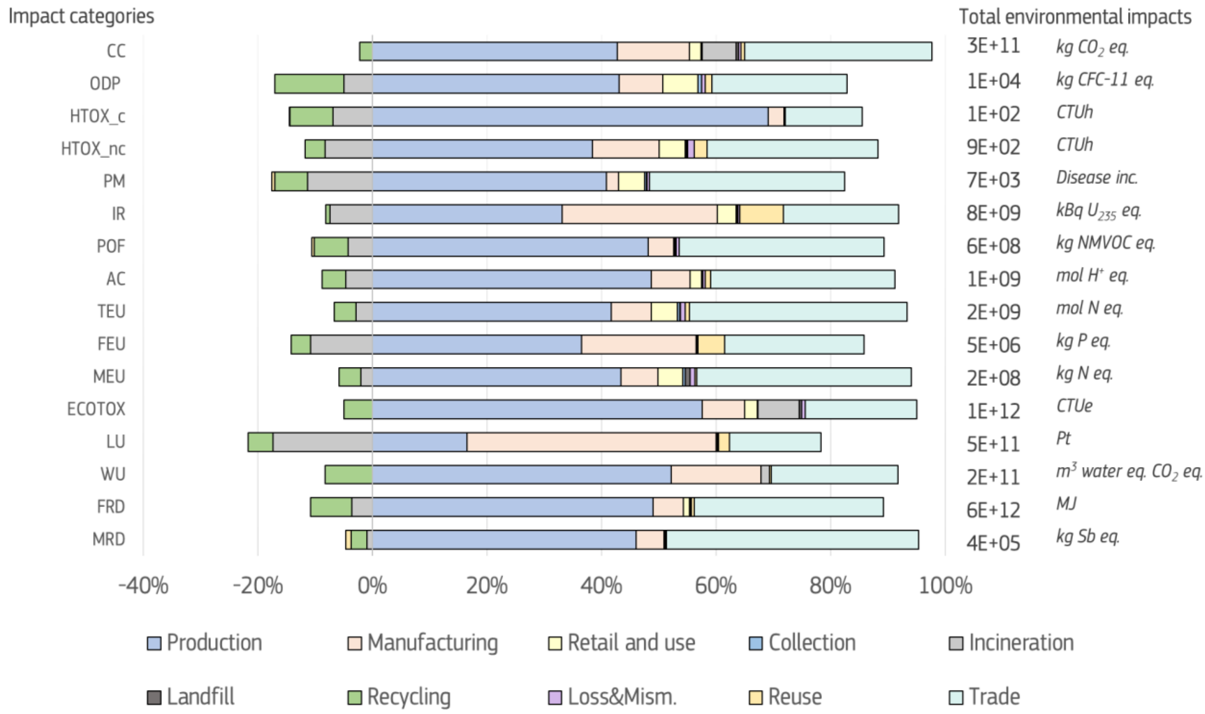


Source: JRC elaboration. Note: nodes name are explained in Figure 4.

3.4 Life Cycle Assessment results

In this section the life cycle assessment results for the EU plastic value chain are described, considering the assumptions explained in Section 2.5. An overview of the life cycle impacts of the 2022 EU plastic value chain is provided in Figure 9.

Figure 9. Life cycle impacts of the whole 2022 EU plastic value chain and percentage contribution to 100% of each impact category and life cycle stage. The same legend applies to all bar charts.



Source: JRC elaboration. Note: Loss&Mism = Losses and Waste Mismanagement; CC = Climate Change; ODP = Ozone Depletion Potential; HTOX_c = Human Toxicity, cancer; HTOX_nc = Human Toxicity, non-cancer; PM = Particulate Matter; IR = Ionizing Radiation, human health; POF = Photochemical Ozone Formation, human health; AC = Acidification; TEU = Eutrophication, Terrestrial; FEU = Eutrophication, Freshwater; MEU = Eutrophication, Marine; LU = Land Use; ECOTOX = Ecotoxicity, Freshwater; WU = Water Use; FRD = Resource Use, Fossils; MRD = Resource Use, Minerals and Metals.

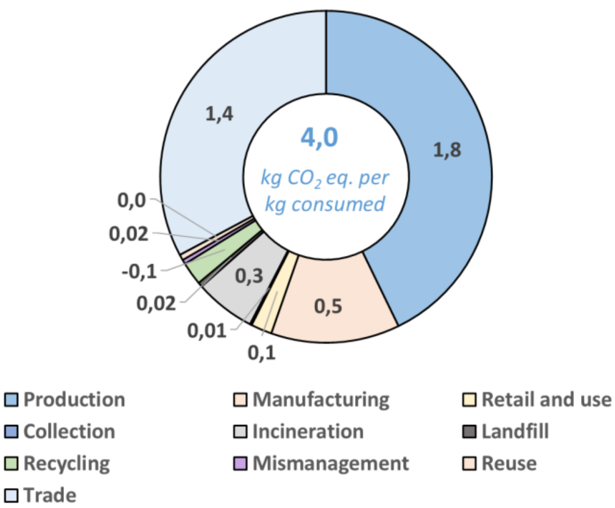
The findings illustrated in Figure 9, revels that production, manufacturing and trade are the key drivers of overall value chain impacts. These results are consistent with previous research by Tenhunen-Lunkka et al. (2023), Systemiq (2022), and Vito (2021). These studies covered a variety of sectors and polymers (albeit not capturing less-explored sectors such as the Fishing and Healthcare sectors) along the whole life cycle of plastics (from production to end-of-life), but especially focused on the sole impacts due to green-house gases emissions.
Notably, the majority of impacts related to trade are attributed to virgin plastic production and manufacturing occurring outside the EU and then imported (26.3 Mt). Concerning other life cycle stages, impacts of waste mismanagement practices are especially evident for 'Human Toxicity, non-cancer'. These impacts are largely linked to the export and poor management of mismanaged waste via e.g. open burning and open dump of waste. About the Climate Change impact category, the whole value chain exhibits total emissions amounting to 252.1 Mt_{CO_2} eq., with Packaging leading the sector-specific contribution with 29.0% of the total impacts. By comparison, 208 Mt_{CO_2} eq. were estimated by EIONET (2021) for the EU plastic value chain in the year 2018 (a value echoed by Tenhunen-Lunkka et al., 2023; and Vito, 2021), although considering different system boundaries.

The environmental impacts related to preparation and reuse stage of the Transport and Textiles sectors is primarily due to the maintenance of vehicles and the energy needed for washing textiles. In this stage, impacts are especially relevant for 'Ionizing Radiation, human health' category, despite (negligible) credits were estimated for both sectors (Annex 2.1).

For the impact categories under examination, the benefits of the value chain come from recycling and incineration with energy recovery activities. In fact, out of the total plastic production equal to 57.9 Mt, only around 36.6 Mt of waste are properly collected at the end-of-life, and an even smaller quantity (slightly above 11 Mt) are sent to mechanical recycling facilities, therefore leading only to marginal savings. A notable example of this disparity can be seen in the Packaging sector, as for every kilogram of plastic produced (and consumed in the EU territory), approximately 2.2 kg_{CO_2} eq. were emitted. By contrast, -0.8 kg_{CO_2} eq. are saved per kg of plastic sent to (mechanical) recycling. This highlights both the need of a more effective upstream waste collection and management coupled with an improvement of recycling strategies/technologies to mitigate the environmental impacts of plastic production and use.

Concerning the whole plastic value chain, this study revealed that incineration contributed to 15.6 Mt_{CO_2} eq., compared to the –5.9 Mt_{CO_2} eq. total net savings for the recycling of plastic in the EU. However, it is worth to note that when considering some of the impact categories beyond Climate Change, the benefits of incineration may surpass those of recycling (Figure 9). It is also important to mention that the recycling life cycle stage encompassed the management of recycling residues, which were either incinerated or landfilled. Nonetheless, this disparity could be especially attributed to higher mass of plastic waste still incinerated in the MFA 2022 in the EU plastic value chain (23.1 Mt), compared to the 11.4 Mt managed by all recycling facilities. Approximately 25.3% of plastic waste entering recycling facilities is sent to incineration, with variations depending on sectors and polymers. Based on the total life cycle impacts calculated, and considering the EU-27 population for 2022 derived from Eurostat (Eurostat, 2022), the impacts for Climate Change can be translated to around 564.3 kg_{CO_2} eq./person. Considering the same population, results indicated that around 139.4 kg of plastics are consumed per-capita yearly, as a consequence of the total 62.8 Mt of plastics consumption of the EU plastic value chain (higher than production amounts consequently to positive products trade balances; Section 3). According to these findings, about 4.0 kg_{CO_2} eq. were emitted per kg of plastic consumed: a breakdown of the per-capita results associated with the Climate Change impact category are provided in Figure 10.

Figure 10. Per-capita life cycle impacts of the 2022 EU plastic value chain and percentage contributions – Climate Change impact category.



Source: JRC elaboration.

4 Conclusions and recommendations

This study aimed at establishing a Material Flow Analysis model (MFA) for the whole value chain of plastics in EU-27 in 2022, from polymers production to end-of-life plastic management and recyclates production. This analysis was coupled with a Life Cycle Assessment (LCA) study providing system-wide insights on the environmental impacts related to the plastics value chain, across the 16 impact categories of the Environmental Footprint (EC, 2021).

The MFA analysis focused on sector-specific MFAs for a total of 9 sectors (namely: Packaging, Construction, Transport, Electronic, Agriculture, Textiles, Healthcare, Fishing and 'Other'), through a top-down approach. Thanks to the granularity of data achieved in this study, these sectors were further detailed via polymer-specific MFAs, capturing a total of 15 different polymers (namely: LDPE, HDPE, PP, PS, EPS, PVC, PET, PUR, ABS, PA, PMMA, PC, bio-PP, bio-PUR, and CA).

Results of the sector-specific MFA highlighted a plastic production volume equal to 57.9 Mt (of which 98.9% related to fossil-based and 1.1% to biopolymers). During the production and manufacturing life cycle stages, 5.4 Mt pre-consumer waste was generated (9% of the total plastic being manufactured) and ultimately separately collected. Meeting the total plastic consumption needs (equal to 62.8 Mt) was possible solely through the additional imports of plastic products and polymers, on top of the total quantities of plastic products manufactured within the EU territory. Of the total quantity of post-consumer waste generated (42.5 Mt), only 41.5% was separately collected (of which 41.7% sent to recycling facilities). A significant fraction (42.0%) was still collected as a mixed waste fraction (and mostly disposed of in landfills or incinerated), with only 4.3% of mixed waste being sent to recycling. Out of the total waste collected (36.6 Mt), incineration and landfilling remained the dominant waste management route in the EU-27, accounting for 43.6% and 22.5% of total waste collected, respectively.

On top of the waste collected as a mixed fraction or separately to incineration, landfill and recycling, other relevant waste streams were identified. Notably, around 8.6% of the total waste generated in the EU (3.6 Mt) was mismanaged, representing the waste fraction inadequately disposed or inappropriately treated/managed. Plastic could not only be mismanaged, but also lost in the environment, accumulating to water and soil as a consequence of microplastic and macroplastic releases along the value chain. Most of the total microplastics and macroplastics losses in all sectors (3.7 Mt) arise during the use phase (43.1% of the total losses) and most (2 Mt) were released to soil (against 0.7 Mt to water), the rest (1 Mt) being recollected. Cumulatively, the total quantity of plastic lost and mismanaged represented 11.4% of the total production (6.6 Mt).

Concerning plastic waste being recycled, a total of 8.4 Mt of secondary plastics (i.e. 'recyclates') were produced in the MFA 2022, with 7.3 Mt being employed by the EU-27 manufacturing industries (as 12.5% of recyclates were exported). 11.4 Mt were sent to recycling (considering 1 Mt of imported recyclable waste), of which 11.1 Mt was sent to mechanical recycling. Chemical recycling represented a potential alternative to mechanical recycling treatments, despite receiving no more than 2.3% of the total plastic sent to recycling each year. Results also indicated that the average end-of-life recycling rate among all sectors (i.e., recyclates produced over total waste being generated) was equal to 19.6% (17.1% when recyclates' trade is considered).

Results of the study underlined the role of Packaging and Construction as the most important sectors among those assessed, respectively contributing to 33.9% and 18.3% of the total plastic consumption. Import of plastic products played a crucial role in driving the overall quantities of plastic volumes consumed in the EU. In particular, import of Textile products contributed around 7 Mt and represented the main responsible for a total trade deficit of 10.7 Mt for the whole EU. Out of total quantity of plastic consumed, the share of plastics being discarded vs. maintained in stock varied depending on the sector under scrutiny. Almost 93% of the Packaging plastic consumption was discarded in the 2022 due to the short lifespan of products in this sector. By contrast, as much as 74.7% of the consumed products in Construction were accumulated as stock.

On top of Packaging (with 19.7 Mt), also the Textiles sector accounted for a significant quantity (6.2 Mt) of the total waste generation due to the relevant imports of textile products. The present study underlined the different role of the various sectors in the total plastic waste collected and especially sent to recycling in the EU. The majority of plastic waste sent to recycling facilities was found to be attributable to waste collected in the Packaging (8.5 Mt) and Construction (0.7 Mt) sectors. Among the various sectors under exam, Packaging and Agriculture manifested the highest recycling rates considering the total recycling plants' outputs out of the total waste generated (33% and 25%, respectively). Such high rates were due to key polymers collected and recycled in these sectors. By contrast, the lowest recycling rates was noticed for the Electronic and Textiles sectors, respectively with 10% and 2%. Details about the fate of recyclates indicated that the Construction sector is the most common destination for secondary plastics, followed by the Packaging sector. The lack of granular information on the fate of plastics underlines how such data would need to be improved. The key contributors to the total plastic lost in the EU included releases from packaging (1.9 Mt), for example due to littering, from tyre abrasion (0.6 Mt), and from synthetic textiles washing (0.15 Mt).

Results of the polymer-specific MFAs suggested that a subset of polymers contributed significantly to the overall plastic consumption, with a significant role especially played by HDPE, LDPE, PP and PET covering 50.2% of the total consumption. Furthermore, the same polymers contributed to a total of 77.3% of all recyclates being generated (pre-exports). The polymer's end of life recycling rate depends on the sector scrutinized. In the case of Packaging, higher recycling rates were identified for HDPE (51.3%) and PET (46.8%).

The modular combination of polymers-specific and sectors-specific MFAs and transfer coefficients enabled the formulation of product-specific overviews. For instance, the analysis of flat screens in the EU-27 revealed that these products contributed to 6.0% of the total recyclates generated for the whole Electronic sector, but only to 0.2% of the total recyclates generated among all sectors. The modularity of this analysis could enable overviews for any key plastic product in the EU plastic value chain, given the availability of its polymers composition.

Environmental impacts of plastics in the EU

Findings of the LCA study revealed that the total Climate Change impacts of the whole EU-27 value chain amounted to 252.1 Mt_{CO_2}eq. Notably, the production and manufacturing stages accounted for a significant share as high as 58.0% of the total impacts (respectively, 113.0 Mt_{CO_2}eq. and 33.2 Mt_{CO_2}eq.). Out of the remaining 42.0% the most significant contribution resulted from the greenhouse gases emissions related to incineration activities (15.6 Mt_{CO_2}eq.).

The Climate Change results of the present study could be translated to around 564.3 kg_{CO_2}eq./person with about 4.0 kg_{CO_2}eq. emitted per kg of plastic consumed (139.4 kg per person). Overall, the Packaging sector alone contributed on average to 29.0% of the total impacts across the various impact categories assessed, resulting in the most impactful sector among all.

In the case of the Climate Change impact category, results indicated that savings were achieved only via recycling activities (-5.9 kg_{CO_2}eq. net savings; mostly consequently to recycling of plastics of the Packaging sector), although both savings from recycling and incineration with energy recovery were visible in other impact categories. Despite environmental savings for Climate Change would be achievable solely through recycling activities, results indicated that the benefits associated to energy recovery during incineration (capturing a total of 23.0 Mt of plastics) might be higher than those of recycling for some other impact categories (e.g. impacts related to the 'Human toxicity, non-cancer' impact category, or impacts due to Ionizing Radiations). The findings related to the end-of-life performance of plastics underlined how the results' interpretation could be influenced by the choice of impact category. In fact, depending on the category under scrutiny the relative performance of different life cycle stages/technologies may vary.

Plastic trade also plays a pivotal role in the EU plastic value chain impacts, with total impacts amounting to 86.6 Mt_{CO_2}eq. (34.3% of the whole value chain impacts for this impact category). The majority of the impacts from trade are attributed to plastics production and manufacturing occurring outside the EU and imported. The life cycle impacts of plastic losses to the environment were not accounted due to a lack of standardised or recognised methodology for assessing these. Moreover, the methodology developed in this study ensured that all life cycle impacts connected with the consumption occurring within a given geography are captured. Such approach ensures a fair comparison among studies implementing the same methodological approach, as it would avoid double counting and ensure comparability. Further, the proposed methodology could be replicated even beyond packaging, representing a potentially relevant asset also for other studies supporting mass and impacts analyses of key value chains in the EU.

Areas for improvement and priority interventions

During the development of the study, key areas in need of improvement were identified. Such areas were not only unveiled when screening available statistics and data, but also because of the discussions with stakeholders during the consultation.
It is evident that future variations in the production of virgin plastics for fossil sources could have a significant role in reducing impacts and improving circularity of the value chain. Remarkably, available statistics on the plastic value chain suggest a decline in plastic production trends from 2018 to 2022, consequently to multiple factors including for instance oil prices fluctuations, global production overcapacities and competition from imports, environmental regulations, consumers' awareness, etc. To reduce the dependency from fossil-based polymers, the presence of bio-based plastics alternatives could also especially be encouraged, although this would require an in-depth analysis of potential trade-offs with regards to impact categories beyond Climate Change.

Enhancing the granularity details concerning imports of plastics could have a pivotal role to differentiate between the influx of primary and secondary plastics in the EU, as particularly flagged by stakeholders during the consultation. The inclusion of bio-based plastics and the tracking of compostable polymers along the value chain proved to be challenging not only due to the few data available (especially with sector-specific granular details), but also due to overlapping definitions in literature (e.g. bio-based vs compostable vs biodegradable).

Notwithstanding the potential trends on the production and imports of plastics, circularity of the whole value chain would only be possible if end-of-life waste collection and waste management are also improved. Notably, information on the origin and fate of recyclates could be improved. Besides, a proper mapping not only of the quantity but also of the fate of pre-consumer waste was recognized as crucial. Improving the data available to account for the pre-consumer waste stream could be essential, especially to assess its contribution to the circularity of the EU value chain. Although existing statistics enable the mapping of waste collected and the associated fate, a lack of data related to the delta between consumed plastics and total waste generated was evident. This is particularly significant as it affected the mapping of stock and mismanaged plastics, both hotspots for a thorough EU-wide overview of flows and impacts.

Developments on the combination/integration of chemical recycling facilities with mechanical ones could also prove to be fundamental. Data indicated the share of chemical recycling facilities in the EU to be negligible compared to mechanical recycling: chemical recycling facilities are currently less developed than mechanical counterparts, as not only in the EU but also globally few large-scale plants exist to date. Scaling-up chemical recycling facilities could significantly influence the circularity of the value chain, especially if such technologies are applied to less-recycled polyolefins, boosting the management of alternative/complementary waste feedstocks that would not be converted into secondary materials otherwise.

The feedback gathered during the stakeholder consultation and the information retrieved through the performed literature review, also revealed that rather than quantifying plastic flows by economic sectors or polymers, most data are commonly presented in an aggregated way. This level of aggregation is especially challenging not only for less-explored sectors (such as Healthcare and Fishing) but also for the more explores ones (such as Packaging and Construction) as it could cause potential discrepancies in results, especially when top-down approaches are combined/compared with bottom-up ones. Further, some key aspects of the plastic value chain are neglected (such as plastic losses and waste mismanagement, on top of trade flows). A harmonization of plastic data collection could enhance the generation of monitoring frameworks to assess the implementation of current policy efforts in the EU value chain and more realistically assess future plastic flows. This could have a strategical role to boost the EU competitiveness and assess the untapped potential for additional and better recycling in the plastic value chain. Although Packaging plays a pivotal role in the whole plastic value chain flows and impacts, the analysis of less-explored sectors should be refined and supported in the next years and should not be underestimated, due to their potential contribution to increase total recycled plastics volumes.

This study represents a key milestone in improving granularity and details of complete overviews of plastic flows in the EU, especially considering that to date, few-to-none studies have combined MFA with Life Cycle Assessment (LCA) to provide a complete overview of flows and impacts of the plastic value chain in the whole EU. Findings of the present analysis are especially valuable as several interactions with stakeholders represented pivotal sources of information to refine estimates and knowledge of a market-adherent overview of the value chain. Future studies could especially focus on improving sector-specific and polymer-specific data for less-explored sectors coupled with a boosted in-depth knowledge of waste mismanagement, trade (of primary/secondary plastic products and polymers), and recyclates' fate.

Overall, the collected insights from the present study could not only assist decision makers in identifying and prioritize areas for interventions but also support researchers and practitioners in delving deeper into those aspects being key assets for future sustainability interventions supporting the shift to a circular plastic value chain.

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List of abbreviations and definitions

Abbreviations	Definitions
ABS	Acrylonitrile butadiene styrene
bio-PP	Bio-based polypropylene
bio-PUR	Bio-based polyurethane
CA	Cellulose acetate
CPA	Circular Plastic Alliance
EC	European Commission
EMAF	Ellen MacArthur Foundation
EPS	Expanded polystyrene
EU	European Union
GDP	Gross Domestic Product
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
MFA	Material Flow Analysis
PA	Polyamides
PC	Polycarbonates
PET	Polyethylene terephthalate
PLP	Plastic Leak Project
PMMA	Poly (methyl methacrylate)
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane

Abbreviations	Definitions
PVC	Polyvinyl chloride
SDG	Sustainable Development Goal
TC	Transfer Coefficient
UNEP	United Nations Environment Programme
WEEE	Waste Electrical and Electronic Equipment
Mismanaged waste	Inadequately managed waste, which could be inappropriately disposed (e.g., disposed in open dumps, in unspecified landfills, unaccounted, etc.), uncollected, and/or inappropriately treated/managed (e.g., by unauthorized third parties) and that could create routes for potential losses and releases in the environment
Plastic loss	The quantity of macroplastic or microplastics that is lost from plastic management processes or by consumers
Plastic release	The quantity of macroplastic or microplastics that is lost from e.g., the production phase, use phase, etc., and is ultimately released to the environment (i.e., the fraction of lost plastic which is not recollected)
Plastic consumption	The quantity of plastics that is consumed by end-users (i.e., "apparent consumption", calculated as semi-finished or finished production minus exports plus imports)
Plastic demand	The total quantity of plastics demanded by plastic converters to manufacture plastic products
Product-specific model	Material flow analysis model where the granularity detail of data is at the level of polymers for a given plastic product in a given plastic sector
Polymer-specific model	Material flow analysis model where the granularity detail of data is at the level of polymers
Recyclates	Secondary plastic (i.e., recycled plastic) being an output of a recycling process
Recycling rate (end-of-life)	The calculated ratio between the recyclates produced and total waste being generated (after exports/imports)

Abbreviations	Definitions
Reuse/Reused	Refers to (i) products ‘being reused’ in the use life cycle stage (not yet discarded) or (ii) the procedures of ‘preparation for reuse’ and ‘reuse’ applying to discarded plastic products at the end-of-life products. The specific meaning is clarified in the ‘context’ column for each question related to ‘reuse’
Losses	Refers to the quantity of plastic that is lost to the environment (e.g., during production steps, such as pellets losses –; during consumption, such as textiles microplastics releases during washing; etc.) or littered at the end of life
Sector-specific model	Material flow analysis model where the granularity detail of data is at the level of plastic sectors
Stock	Refers to products (currently) in use in a specific sector (e.g., the plastic components of laptop bought in 2021 and still in use, in the Electronic sector)
Pre-consumer waste	Refers to waste generated during the production and manufacturing life cycle stages. Differs from post-consumer waste, which is instead generated after use of the plastic product

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Annex 1

1.1. Stakeholder consultation

On April 8th 2024, the JRC conducted a stakeholder consultation (also referred to as the 'first workshop') to collect feedback on the EU plastic value chain and to gather sectors and polymers primary data. This additional methodological step was conducted to improve data quality, refine and critically review the collected data, and enhance the robustness of the results through stakeholders' inputs.

A questionnaire was prepared in Microsoft Excel and distributed to a selection of stakeholders to simplify the data collection and processing. The Directorate-General for Internal Market, Industry, Entrepreneurship and Small and medium-sized enterprises (DG GROW) provided suggestions for potential recipients of the questionnaire, primarily including associations of manufacturers and some non-governmental organisations. These stakeholders were then encouraged to further distribute the questionnaire to other organisations potentially interested. The questionnaire included general and sector-/polymer-specific questions aimed at verifying the assumptions and data used in the 2019 MFA (Amadei and Ardente, 2022), and at gathering data potentially suitable for the goals of the present report. Figure 11 represents the summary of the questionnaire, which is structured with tables to retrieved inputs from stakeholders in terms of data, feedback and references. By the end of the consultation period (from April to June 2024), 7 stakeholders had provided inputs, of which 3 provided inventory data in Excel, while the other 4 referred to other studies and documents that could be useful for this report.

Figure 11. Examples of part of the stakeholder questionnaire sent to stakeholders after the consultation. This table was used to collect general, sector-specific, polymers-specific and topic-specific inputs.

Comments and inputs on the 2019 JRC MFA model

In this sheet you may provide specific comments, data or any other input on the 2019 JRC MFA study. This sheet is divided in section related to sectors and polymers that have been analyzed in the context of the 2019 JRCA MFA study.
A "general" comment section is also included. The respondent can provide any number of replies in any of the below sections.

Links (IN BLUE) in the present sheet - Click to browse to the selected section for your comments

General comments	Sector-specific comments	Polymer-specific comments	Topic-specific comments
General	Included in the MFA model:	Included in the MFA model:	Included in the MFA model:
	Packaging	LDPE	Trade
	Construction	HDPE	Raw materials
	Transport	PP	Manufacturing/production
	Electrical and Electronic Equipment	PS	Finished/Semi-finished products
	Agricuture	EPS	Consumption
	Clothing and textiles	PVC	Reuse
	Healthcare	PET	Stock
	Fishing	PUR	Waste generation
	Other sectors	ABS	Waste mismanagement
		PA	Waste collection
		Other polymers	Recycling
			Incineration
			Landfill
			Losses and micro/macroplastics
			Secondary plastics and recycled content

Comments and inputs on the 2019 JRC MFA model

In this sheet a list of specifc questions is provided.
These questions server the purpose of further improving the 2019 MFA Model on specific aspects., data or any other input on the 2019 JRC MFA study.

Links in the present sheet - Click to browse to the selected section for your comments

Waste Recycling and Recycled material use
Reuse
Bio-Plastics
PET bottles
Passenger car and trucks
Electrical Equipment
Textiles

Source: JRC survey tool.

All data received were carefully analysed and considered for the modelling of the case studies where possible (in Table 4 stakeholders' inputs/suggestions covered by the 2022 MFA model are provided). Further follow-up exchanges with some stakeholders and further data gathering and refinement were conducted in September and October 2024.

Table 4. Noteworthy stakeholders' inputs/suggestions included in the 2022 MFA and retrieved from stakeholder exchanges between April 2024 and October 2024.

Sector	Input from the consultation accounted in the analysis	Input details
All sectors	Aggregated 'semi-finished' and 'finished' products	Specific stakeholder feedback
All sectors	Sector-specific polymer's share	Suggested reference: Plastics Europe report (2024)
All sectors	Insights on pre-consumer waste	Specific stakeholder feedback
All sectors	Bio-based plastics demand	Suggested reference: Plastics Europe (2024) and Renewable carbon (2023)
Transport	Quantity of reused products related to 'preparation for reused and reuse' flow	Suggested reference: Conversio Market & Strategy report, 2022
Fishing	Assumptions on waste collection and stock	Specific stakeholder feedback
Healthcare	Healthcare packaging share	Specific stakeholder feedback

Source: JRC elaboration.

During the first workshop, participants assessed the MFA 2022 project as particularly useful to their work and organisation (8.4 on a scale of 10). The participants stated that the project could provide more transparency and additional data on the EU market state of play for recycled plastics. Several stakeholders considered this could help track the availability and quality of recyclates.
The participants identified the following as the most three important aspects to improve in the MFA 2022 compared to the earlier edition (MFA 2019; Amadei and Ardente, 2022):

- The granularity of the data on the end-uses of the recyclates and the recycling technology employed. Several participants stressed the need to trace materials flows by polymer and by application, and not only by sector (application-specific polymers, but the main polymers also mentioned being Polyethylene (PE), Polyethylene Terephthalate (PET), Polypropylene (PP), Polystyrene (PS), Polyamide (PA), Polyurethane (PU), Polycarbonate (PC).

- The data on imports and exports of recyclates. Several participants suggested the MFA should help track imports to the EU, including virgin and recyclates as well as, in the future, recycled hydrocarbons imported as feedstock. This was highlighted as particularly challenging in the absence of specific Harmonised System (HS) codes for recyclates.

- The estimates on plastic waste lost to the environment or mismanaged, with consideration of its ultimate disposal to environmental compartments.

On the December 6th 2024, the JRC organized a second workshop to inform stakeholders of the progress made, presenting the key preliminary results of the 2022 MFA and acknowledging the remaining data gaps. The workshop was an interactive session attended by around 50 stakeholders, which rose several questions and provided their feedback. Following the workshop, the JRC addressed each comment received and prepared a comprehensive reply to each question via email. In conclusion, JRC has collected a few key takeaways from these events, such as the importance of promoting a comprehensive overview of the plastic value chain and essential for clarifying terminology and informing future research. These aspects are spotted thanks to feedback received through questionnaires, which provided reports and primary data of which few are integrated in the plastic MFA model.

1.2. Transfer coefficient approach

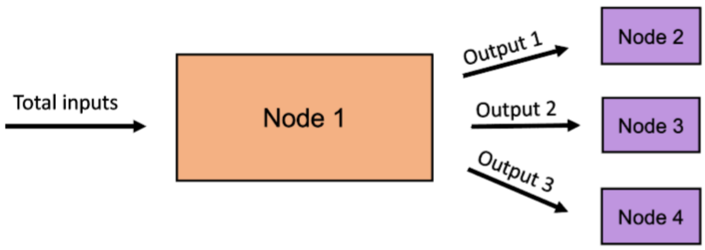
The present study leveraged Transfer Coefficients (TCs) to ensure mass balance among the various steps of the plastic life cycles (also identified with value chain 'nodes'; Figure 12). Said TCs were calculated according to the following equations (Equation 2). A TCs is a percentage that allows an allocation of the total quantity of a substance transferred between processes. In this study, TCs are calculated as the ratio of outputs to inputs for a given node, ensuring that the total mass balance among nodes is maintained. TCs related to export flows were included in the total of the flows exiting nodes (i.e. they contribute to the 100% of outputs). TCs related to imports were used to calculate the total mass of a given node on top of the flows received from previous nodes in the value chain (i.e. the total plastic mass in the node 'consumption' includes flows of imported products on top of those related to manufactured plastics).

Equation 2. Transfer coefficients (TCs) calculations

$$TC_{k,j\ [import,\%]} = \frac{Import\ flows_{[Mt]}}{Total\ inputs_{[Mt]}}$$

$$TC_{k,j\ [\%]} = \frac{\Sigma\ Total\ outputs_{[Mt]}}{\Sigma\ Total\ inputs_{[Mt]}}$$

Figure 12. Simplified diagram of the nodes and flows of the material flow analysis as intended in the present study.



Source: JRC elaboration.

In the present study TCs were obtained through several approaches. In particular, TCs could be gathered via: (i) direct extraction from literature, where a specific percentage value was already available for a particular step in the value chain and sector; (ii) calculation based on ratios derived from literature data (expressed in mass units); or (iii) internal assumption, used when no other specific information was available.

1.3. Sectors-specific assumptions

The sectors-specific MFAs leveraged a top-down approach starting from the total 2022 EU plastic production. As outlined in Table 5, this approach primarily relied on statistical data from Plastics Europe (Plastics Europe, 2024), for both the total plastic production volume and its sector-specific allocation. Employing a top-down approach in place of a bottom-up one ensured the coverage of all flows in the EU, although findings are directly dependant on the choice of the data sources for the estimation of plastic production.

As anticipated in the methodology section (Section 2), the scope of the Plastics Europe report (Plastics Europe, 2024) was not aligned with the broader one employed in this study. This discrepancy was solved by including additional plastic production streams (notably, textiles, adhesives and paints) to the scope of those reported by Plastics Europe, 2024. The total plastic production for Textiles was retrieved from a technical report published by the Joint Research Centre (Huygens et al., 2023). This recent study performed an MFA to estimate and map textiles flows in the 2019 EU, capturing end-of-life flows as well as estimating textiles production quantities. Plastics production volumes associated with products such as adhesives and paints were estimated via specific PRODuction COMmunautaire (PRODCOM) codes (Eurostat, 2022) and included in the 'Other' sector. To this goal, PRODCOM entries related to self-adhesive plates including code n.22292140 *(Self-adhesive plates, sheets, film …. in rolls <= 20 cm wide (excluding plastic strips coated with unvulcanised natural or synthetic rubber))* and n.22292240 *(Self-adhesive plates, sheets, film, ….. whether or not in rolls > 20 cm wide (excluding floor, wall and ceiling coverings of HS 3918))* were employed. Another aspect worth mentioning is that the Plastics Europe report (Plastics Europe, 2024) aggregated Fishing and Healthcare under a common sector. However, as such sectors were uniquely identified in the present study, PRODCOM data (Eurostat, 2022) were employed to map them in unique and specific following the same approach suggested by the 2019 MFA. All the data fetched from Plastics Europe, (2024) were corrected in terms of geography (since Plastics Europe refers to EU-27+3) with the approach detailed in Section 2.3.

Table 5. Sector share and total mass of plastic production in EU-27 for the reference year 2022.

Sectors	Share (%)	Plastic production (Mt)	Reference
Packaging	37.9%	21.93	Plastics Europe (2024)
Building	22.3%	12.87	Plastics Europe (2024)
Automotive	8.1%	4.67	Plastics Europe (2024)
Electronic	5.5%	3.20	Plastics Europe (2024)
Agriculture	4.3%	2.47	Plastics Europe (2024)
Textiles	2.7%	1.55	Huygens et al. (2023)
Fishing	0.3%	0.18	Eurostat (2022)
Healthcare	0.4%	0.21	Eurostat (2022)
Other	18.6%	10.77	Plastics Europe (2024)
Total (All sectors)	100%	57.85	-

Source: data elaboration from Plastics Europe (2024), Huygens et al. (2023) and Eurostat (2022).

For each life cycle step of the EU plastic value chain, a summary of the key assumptions and literature sources used to estimate TCs are explained in the following paragraphs. The TCs employed in the model are indicated in Table 6.

<u>Plastic products manufacturing and consumption</u>

To map the bio-based polymers' flows in this study, the total quantities of bio-based plastics produced in the EU were retrieved from Nova-Institute (Renewable carbon, 2023). Such quantity was then allocated to the different sectors of the study, via sectors-specific shares fetched from the 'Plastic Recycling Factsheet' provided by the European Recycling Industries' Confederation (EuRic, 2020).

A bottom-up approach was employed to estimate trade-related data (i.e., imports and exports) across all sectors. This methodology involved modelling the trade flows of primary plastics and plastic products using specific PRODCOM codes (Eurostat, 2022) for the reference year 2022. Polymer-specific PRODCOM codes of primary plastics were classified by polymer, while products-specific codes were categorized by sector and were used to calculate the TCs for import and export flows (of both the production and manufacturing stages). The export of plastic waste was modelled according to the approach outlined in the 2019 MFA (Amadei and Ardente, 2022), that relies on Eurostat data.

Based on the findings gathered from a literature review on the topic, it has been acknowledged that a certain quantity of 'pre-consumer' waste is generated during the manufacturing stage, as reported for instance by Cimpan et al. (2021) and Plastics Europe (2024). However, the available sources do not provide a thorough overview of the EU-wide entity of these flows, but rather typically focuses solely on specific sectors of products. A dedicated approach was therefore developed in the present study to estimate the total volumes of pre-consumer waste being generated. This approach was based on the quantities of recyclates generated from the management of pre-consumer waste reported by Plastics Europe (2024). Starting from that figure, the masses were allocated from the end-of-life stage of the value chain to the upstream, calculating flows 'in reverse' (via e.g. the efficiency of mechanical recycling).

After the manufacturing stage, each plastic products put in the market and consumed is associated with a specific lifespan. Such lifespan could vary according to the associated purpose to each product. In fact, some plastic products (such as mono-use packaging products) may be discarded immediately after one use and therefore contribute to the total quantity of waste generated in the same year of consumption. By contrast, other may be kept in stock for extended periods as they will be discarded in future and not in the same year when consumption occurred. As the present study accounts for a yearly 'snapshot' of the plastic value chain, the 'stock variation' is calculated as the delta between consumption and waste generation and calculation provides insight into the net accumulation or depletion from stock of plastics in the system.

Management of collected waste

As mentioned in Section 2.4.1 the total plastic waste generated in the EU was calculated by summing waste collected, waste exported, waste lost and waste mismanaged flows. The total quantity of waste generated can be collected either separately or as a mixed fraction, sent to composting facilities or 'prepared for reuse and reused'.

The quantity of collected waste was retrieved from Plastics Europe (2024) for the following sectors: Packaging, Construction, Transport, Electronic, Agriculture and 'Other'. In the case of Textiles, data on waste collection were retrieved from Huygens et al., (2023). By contrast, the waste collection for Healthcare and Fishing was assumed equal to the waste generation quantity minus the mismanaged waste portion. Consequently, in the case of Healthcare and Fishing sectors was not accounted waste generation exported and lost in the environment due to lack of data.

For Construction, Transport and Healthcare it was assumed that the entirety of the waste collection was managed as a separated stream. This assumption considered that plastics products in these sectors were primarily involved by industrial consumption, which usually leads to by-pass consumers' behaviour, resulting in separate waste management flow. In contrast, for Packaging, Electronic and Agriculture the share of separate and mixed waste was estimated based on Plastics Europe (2024). For the Textiles sector assumptions on separate and mixed waste relied on Huygens et al. (2023), while for Fishing and 'Other' were based on Watkins et al. (2020).

On compostable plastic waste, it was considered that polymers as CA, PBAT, PHA and PLA could be mapped as 'compostable' as suggested by Nizamuddin et al. (2024). To bypass the lack of data on the quantity of plastics sent to composting facilities in the EU, an internal assumption was necessary. It was assumed that 50% of the total compostable plastics is sent to composting facilities in the 2022 EU-27 plastic value chain. This assumption considers potential contamination with impurities of the compostable plastics, leading to significant quantities of plastic volumes to not be treated in composting facilities. Further, the assumed percentage also entails the possible citizen disposal

errors and the possible limited public awareness on how to properly dispose these type of plastic products (Raźniewska, 2022).
As stated in Section 2.4.1, certain plastic waste products could be reuse after maintenance and have been therefore mapped under the 'preparation to reuse and reuse' flow. This flow was estimated via sector-specific data, to properly capture any potential sector-specific differences on how such plastics are handled. In the case of Electronic, the total mass of reused plastic was estimated as in the 2019 MFA (Amadei and Ardente, 2022) based on Seyring et al. (2015). In the case of the Transport, the quantity of reused plastics in this sector was derived from data available in a sector-specific report (Linder et al., 2020) suggested by stakeholders during the consultation. This report provides insights on the total volumes of reused plastics in the Transport sector during the year 2022 for Germany. Lastly, in the case of Textiles, the quantity of reused plastics was retrieved by a recent JRC report (Huygens et al., 2023), which provided figures based on 'cleaning' and 'repairing' data of clothes and textiles.
The study included waste incineration with energy recovery and landfill as final disposal, on top of composting and recycling.. Notably, a portion of the incinerated plastic waste may be found in the bottom ash. In this model, it was considered that part of the incinerated plastic could remain in the bottom ash and be ultimately landfilled (as suggested also by Yang et al., 2021): such quantity (i.e., the transfer coefficient of plastic waste from incineration to landfill) was calculated from data by Garcia-Gutierrez et al. (2023).

Losses and mismanaged waste

The potential plastic losses (of both micro-plastics and macro-plastics) that may occur at various steps along the plastic value chain were mapped and analysed in the present study, employing a wide array of sources. Losses occurring during the following life cycle stages were mapped:

- **Plastic production and manufacturing**: in this stage TCs were retrieved as described in the 'loss and release' methodology from the 'Plastic Leak Project' (Peano et al., 2020). This approach provides methodological guidance to map the environmental losses of plastics (occurring at different life cycle stage), following the associated fate towards the final environmental compartment of release (e.g. soil, water). With regard plastic losses associated to Textiles and 'Other', various sources were employed. The losses related to Textiles were retrieved from Kounina et al. (2024), which provided a comprehensive assessment of the global apparel industry's contribution to plastic pollution. The textiles losses were estimated based on the average losses of synthetic fibres during industrial clothes washing considering high- and low-income EU countries. In the context of providing estimates on losses for the 'Other' sector, a recent Impact Assessment report (Staff Working Document - SWD, 2023) supporting the development of an EC Regulation on microplastics pollution (EC, 2023b) was explored. This study was used to calculate the losses of plastics deriving from paints, a product typically manifesting a significant plastic content (37%) and that can be found on a wide range of products.
- **Plastic consumption**: with regard plastic losses associated to Textiles, insights from Kounina et al. (2024) were employed also for this life cycle stage. The study from Kounina et al. (2024) provides an approach to assess the potential losses due apparel washing during consumption. In the case of the 'Other' sector, data from EC 2023 were also employed to calculate losses occurring from paints during consumption. The same EC 2023 was also employed to capture data related to losses in the context of the Transport sector. Based on the EC 2023 study, specific losses of microplastics occurring due to the friction between tyres and the road surface were accounted (considering different vehicle types ‐ e.g. motorcycle or passenger car ‐; road types ‐ e.g. urban or rural ‐ and road surfaces specificities). For the remaining sectors, data from Kawecki and Nowack (2019) were employed (following the

same approach described in Amadei and Ardente, 2022). Plastic losses during consumption especially focus to unintentional losses (such as those related to clothes washing) and littering events. During a littering event, a plastic product is typically discarded 'on-the-go' mostly as a consequence of improper consumers' behaviours. Such event is especially significant for short-lived and single-use plastic products, such as plastic bottles. In the present study, losses due littering have been mapped in the 'consumption' life cycle stage, albeit a lack of agreement on the terminology has been recognized in the consulted literature. In fact, notwithstanding the different definitions of a 'littering event' available among sources, littering could be mapped to either 'consumption-/use-related' life cycle stages (to stress the moment in which such event occurs) or to 'waste-related' life cycle stages (to stress the fact that the event refers to a product being discarded). and because of the inherent durability of materials like plastics. Further studies could focus on improving the specific allocation of plastic losses flows among consumption/waste life cycles and providing a specific definition/differentiation of littering event.

- **Plastic waste**: similarly to previous life cycle stages, data related to losses of plastic waste were retrieved from the Plastic Leak Project (Peano et al., 2020), for all sectors under scrutiny beside 'Other'. In the case of the 'Other' sector, losses were mapped according to the EC 2023 (and are based on estimates concerning poor management during the end-of-life, as an example consequently to the practices such as vessels' shipbreaking). Plastic waste losses cover unintentional losses that could verify during waste management. Further accidental environmental conditions, such as wind and water, could disperse materials from managed systems into the environment. Losses related to waste but that underline a level of 'intentionality' (e.g. waste is purposely transported and disposed in an illegal dumpsite, etc.) are instead captured among losses occurring during plastic waste mismanagement. The estimation of plastic losses being recollected was based in the present study on data from Kawecki and Nowack (2019) and Peano et al. (2020). It is worth noticing that few statistics related to plastic losses recollection in the EU are currently available. As an example, the abovementioned references provide information related to plastics losses collected e.g. as retentate in wastewater treatment sludge or in storm water management sludge or approaches to estimate lost plastic recollection via e.g. street cleaning. As all these factors are strongly locally and geographically specific, a single estimate related to the total waste lost being recollected in the EU might be complex to obtain. For instance, Kawecki and Nowack (2019) employed assumptions attributable to the Swiss geography with regards to street cleaning operations, which may lead to a conservative estimate concerning total losses of plastics in the environment for the EU. As a consequence, new data available concerning lost plastics being recollected should be prioritized when updating plastics flows analysis of the EU in the future.

- **Plastic waste mismanagement**: as further described in the following paragraphs of this section, part of waste follows improper/illegal waste management and was mapped in the present study as a 'waste mismanagement' flow. Part of the mismanaged waste could ultimately be dispersed into the environment. Losses occurring to the fraction of waste mismanaged were mapped according to the Plastic Treaty Futures report (Systemiq, 2024).

In the present study, the flow related to mismanaged waste was estimated based on the country-specific Mismanaged Waste Index (MWI), retrieved from (Peano et al., 2020 and Kaza et al., 2018). This parameter represents the share of plastic waste that is disposed through inadequate practices. The MWI index provided by Peano et al. (2020) was recalculated in the present study an adapted to the scope of the analysis. To do so, an average MWI for the EU-27 countries (Equation 3) was calculated. The MWI was estimated using country-specific shares of mismanaged waste practices, which were corrected with the volumes of country-specific plastic waste generated per capita (Equation 3).

Equation 3. Mismanaged Waste Index (MWI)

$$MWI = \frac{\sum(Plastic\_waste\_capita_i \; x \;\; MWI_i)}{TOT\_plastic\_waste\_capita_{EU}}$$

Where:

- Plas_Waste_Capita j = Plastic waste country-specific (j) per capita (Eurostat, 2022);
- MWI j = Mismanaged waste index country-specific (j) (Peano et al., 2020);
- TOT_Plastic_Waste_Capita EU = Total plastic waste generated from EU-27 countries (Eurostat, 2022).

Further, specific assumptions on the potential fate of the mismanaged waste were introduced, considering its potential destination and disposal via unsanitary landfilling, and open dumping (11%, and 10%, respectively; Systemiq, 2024). Additionally, 7% of the total mismanaged waste was assumed to be ultimately lost in the environment, according to Systemiq (2024).
However, despite available data hindered the differentiation of waste mismanaged in the EU territory or exported outside EU. Such choice could also influence the estimation of the environmental impacts related to the waste mismanaged in the EU (details on the approach employed to assess the environmental impacts of mismanaged waste of the present study are provided in Annex 2.1).
A dedicated approach was instead applied for the estimation of waste mismanaged in the Electronic sector. In this case, the share of mismanaged waste arising from the total waste generated was calculated directly from Huisman et al. (2015). This study provides insights on the volumes of electronic waste mismanaged by unauthorized collection systems or following unknown management routes.

<u>Recycling and recyclates production</u>

Specific assumptions on recycling treatments were employed to model chemical and mechanical recycling facilities across all EU economy, excluding the Healthcare sector.

- Data related to waste collected sent to mechanical were retrieved from Plastics Europe (2024) and were mapped specifically for the Packaging, Building, Transport, Electronic, Agriculture and 'Other' sectors. The remaining sectors Fishing and Textiles were mapped respectively from Watkins et al. (2020) and Huygens et al. (2023). The mechanical recycling efficiencies adopted in this study (and employed to calculate recycling facilities' outputs – i.e. 'recyclates') were retrieved from Antonopoulos et al. (2021) and Lase (2023). Each sector-specific recycling efficiency was calculated considering the polymers-specific recycling efficiency of each sector (retrieved from the abovementioned sources), weighted by the relative importance of the polymer-specific waste amounts sent to mechanical recycling in each sector. As a consequence, insights related to polymers-specific recycling efficiencies were adopted not only to estimate the recycling efficiencies at the level of polymers' models, but also at the level of sectors' models. For the Packaging sector, data from Antonopoulos et al. (2021) were employed. In the study from Antonopoulos et al. (2021), primary data from sorting plants and recycling facilities for plastic packaging waste are provided, with a focus on specific polymers such as polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), high-density polyethylene (HDPE), and polyvinyl chloride (PVC). Additionally, data related to EPS recycling efficiency in the packaging sector were also included, as reported by Lase (2023). Data retrieved from Lase (2023) were used to estimate recycling efficiencies for the polymer-specific and sector-specific models associated to the Construction, Transport, Electronics and Agriculture sectors. Regarding the remaining sectors and associated polymers (namely: Textiles, Fishing and Other), an average recycling efficiency per polymer, based on the sectors analyzed by Lase (2023) was calculated.

- Data associated to waste sent to chemical recycling were collected for specific sectors as reported by Plastics Europe (Plastics Europe, 2024; i.e., Packaging, Construction, Transport, Electronic, Agriculture and 'Other'). In fact, the penetration of chemical recycling facilities in the EU market was still limited in 2022, as acknowledged for instance by Rizos et al. (2023). For the remaining sectors (i.e. Fishing and Textiles), it was assumed that the plastic waste recycling occurred via mechanical treatment due to lack of specific data associated with chemical recycling. In the present study, chemical recycling efficiencies were estimated based on the results of the study from Garcia-Gutierrez et al. (2023) that collected primary data on chemical recycling facilities based on specific stakeholders' inputs.

On top of the waste generated within the EU territory and sent to recycling facilities, a certain quantity of recyclable waste could also be imported, as acknowledged by Plastics Europe (2024). Based on the findings of Plastics Europe (2024) the import of plastic waste was calculated and included for the following sectors: Packaging, Construction, Electronic, Agriculture and 'Other'. Data from Huygens et al. (2023) were used instead to map imports of recyclables for the Textiles sector.

After recycling activities, recyclates could either be used by the EU manufacturing industries or exported (this flow was estimated according to Plastics Europe, 2024). For the fraction being used within the EU territory, as outlined in Section 2, the present study accounts for the specific recyclates 'fates'. Such 'fates' capture the sector of 'destination', meaning the sector in which recyclates could be used to manufacture new products.
The recyclates 'fates' associated to the Packaging, Construction, Transport, Electronic and Agriculture sectors were retrieved from Souder et al. (2024). In particular, the report from Souder et al. (2024) provides details on (i) the quantity of waste sent to recycling for a given plastic sector and (ii) the recyclates that are then employed to manufacturing new plastic product in a sector (that could be the same of the origin of the waste or a different one).
By contrast, recyclates originated from the Fishing and the Textiles sectors were retrieved from Watkins et al. (2020), a study that aiming at investigating the potential fate of plastic recyclates. Lastly, the plastic recyclates fate from the 'Other' sector, were allocated as suggested by Plastics Europe (2024).

Table 6. Summary of the Transfer coefficients (TCs) adopted for modelling plastic material flows at sectors level in the European Union (EU-27) for the year 2022. Possible rounding effects in the data.

FROM	TO	P	C	T	E	A	TEX	F	H	O
Polymers production	Virgin polymers	98.3%	99.7%	98.3%	99.6%	100.0%	93.5%	100.0%	100.0%	99.5%
Polymers production	Bioplastics	1.7%	0.3%	1.7%	0.4%	0.0%	6.5%	0.0%	0.0%	0.5%
Import polymers	Demand	20.1%	9.0%	20.2%	20.6%	18.0%	99.7%	5.1%	6.8%	17.3%
Demand	Export polymers	12.0%	11.4%	22.9%	22.7%	15.3%	32.0%	8.5%	11.9%	16.7%
Manufacturing	Consumption	90.6%	88.8%	92.5%	93.3%	92.5%	88.6%	99.9%	99.9%	90.4%
Manufacturing	Export Products	11.2%	12.8%	21.0%	8.4%	16.1%	29.6%	11.6%	19.9%	9.2%
Import Products	Consumption	10.3%	15.6%	36.5%	17.3%	8.9%	302.7%	8.5%	44.7%	19.8%
Manufacturing	Pre-consumer waste	9.3%	11.1%	7.4%	6.6%	7.4%	10.7%	0.0%	0.0%	7.8%
Pre-consumer waste	Separated waste	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	0.0%	100.0%
Manufacturing	Losses manufacturing	0.1%	0.1%	0.1%	0.1%	0.1%	0.7%	0.1%	0.1%	1.8%
Losses manufacturing	Microplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Losses manufacturing	Macroplastics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Microplastics	Water	17.0%	17.0%	17.0%	17.0%	17.0%	5.0%	17.0%	17.0%	53.2%
Microplastics	Soil	69.0%	69.0%	69.0%	69.0%	69.0%	95.0%	69.0%	69.0%	32.8%
Microplastics	Recollected	14.0%	14.0%	14.0%	14.0%	14.0%	0.0%	14.0%	14.0%	14.0%
Macroplastics	Water	26.7%	26.7%	26.7%	26.7%	26.7%	76.5%	26.7%	26.7%	26.7%
Macroplastics	Soil	59.3%	59.3%	59.3%	59.3%	59.3%	7.7%	59.3%	59.3%	59.3%
Macroplastics	Recollected	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%
Consumption	Waste generated	92.6%	24.7%	50.4%	85.8%	69.8%	72.0%	42.3%	95.8%	62.7%
Consumption	Losses consumption	4.7%	0.6%	9.4%	0.0%	1.0%	0.2%	3.8%	4.2%	0.1%
Losses consumption	Microplastics	50.0%	9.3%	100.0%	0.0%	10.1%	100.0%	0.0%	0.0%	0.0%
Losses consumption	Macroplastics	50.0%	90.7%	0.0%	0.0%	89.9%	0.0%	100.0%	100.0%	0.0%
Microplastics	Water	0.0%	0.3%	16.7%	0.0%	0.0%	72.0%	0.0%	0.0%	61.9%

FROM	TO	P	C	T	E	A	TEX	F	H	O
Microplastics	Soil	100.0%	95.9%	70.8%	0.0%	37.8%	25.0%	0.0%	0.0%	38.1%
Microplastics	Recollected	0.0%	3.8%	12.5%	0.0%	62.2%	3.0%	0.0%	0.0%	0.0%
Macroplastics	Water	0.3%	0.4%	0.0%	0.0%	0.0%	0.0%	90.0%	0.4%	31.0%
Macroplastics	Soil	8.2%	20.9%	0.0%	0.0%	51.9%	0.0%	10.0%	25.7%	69.0%
Macroplastics	Recollected	91.6%	78.7%	0.0%	0.0%	48.1%	0.0%	0.0%	73.9%	0.0%
Waste collected	Prep. To Reuse and Reuse	0.0%	0.0%	9.2%	2.0%	0.0%	13.7%	0.0%	0.0%	0.0%
Consumption	Stock	2.7%	74.7%	40.2%	14.2%	29.3%	27.8%	53.9%	0.0%	37.2%
Waste generated	Export waste	2.3%	12.0%	4.4%	0.0%	1.9%	10.4%	0.0%	0.0%	3.1%
Waste generated	Waste collected	89.8%	77.3%	63.1%	70.0%	93.3%	88.4%	92.0%	97.0%	90.0%
Waste collected	Mixed waste	36.6%	0.0%	0.0%	48.1%	49.2%	74.5%	52.0%	0.0%	92.7%
Waste collected	Separated waste	62.9%	99.1%	88.1%	49.6%	50.8%	11.8%	48.0%	100.0%	6.7%
Waste collected	Composting waste	0.5%	0.9%	2.7%	0.4%	0.0%	0.0%	0.0%	0.0%	0.6%
Waste generated	Losses waste	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
Losses waste	Microplastics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	85.9%
Losses waste	Macroplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	14.1%
Microplastics	Water	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Microplastics	Soil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Microplastics	Recollected	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Water	15.7%	15.7%	15.7%	15.7%	15.7%	21.8%	21.8%	21.8%	15.7%
Macroplastics	Soil	56.2%	56.2%	56.2%	56.2%	56.2%	78.2%	78.2%	78.2%	56.2%
Macroplastics	Recollected	28.1%	28.1%	28.1%	28.1%	28.1%	0.0%	0.0%	0.0%	28.1%
Mismanaged Waste	Recollected	21.9%	0.0%	21.9%	21.9%	0.0%	0.0%	0.0%	0.0%	21.9%
Waste generated	Mismanaged Waste	5.9%	10.7%	32.5%	30.0%	4.8%	1.2%	8.0%	3.0%	6.1%
Mismanaged Waste	Losses mismanaged	19.5%	25.0%	19.5%	19.5%	25.0%	25.0%	25.0%	25.0%	19.5%
Losses mismanaged	Microplastics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

FROM	TO	P	C	T	E	A	TEX	F	H	O
Losses mismanaged	Macroplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Microplastics	Water	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Water	15.7%	15.7%	15.7%	15.7%	15.7%	21.8%	21.8%	21.8%	15.7%
Microplastics	Soil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Soil	56.2%	56.2%	56.2%	56.2%	56.2%	78.2%	78.2%	78.2%	56.2%
Microplastics	Recollected	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Recollected	28.1%	28.1%	28.1%	28.1%	28.1%	0.0%	0.0%	0.0%	28.1%
Mismanaged Waste	Unsanitary Landfill	30.7%	39.3%	30.7%	30.7%	39.3%	39.3%	39.3%	39.3%	30.7%
Mismanaged Waste	Open Dump	27.9%	35.7%	27.9%	27.9%	35.7%	35.7%	35.7%	35.7%	27.9%
Mixed waste	Mechanical Recycling	0.1%	29.0%	0.0%	18.9%	27.9%	0.0%	0.0%	0.0%	6.3%
Mixed waste	Chemical Recycling	0.0%	1.3%	0.0%	1.1%	2.2%	0.0%	0.0%	0.0%	0.1%
Mixed waste	Incineration	63.1%	44.1%	0.0%	50.0%	40.8%	57.8%	60.0%	60.0%	62.5%
Mixed waste	Landfill	36.8%	25.7%	0.0%	30.0%	29.1%	42.2%	40.0%	40.0%	31.2%
Separated waste	Mechanical Recycling	59.1%	16.7%	17.6%	18.9%	27.9%	6.2%	62.0%	0.0%	6.3%
Separated waste	Chemical Recycling	0.7%	0.7%	1.2%	1.1%	2.2%	6.6%	0.0%	0.0%	0.1%
Separated waste	Incineration	34.2%	52.2%	43.7%	50.0%	40.8%	50.4%	27.0%	60.0%	62.5%
Separated waste	Landfill	6.0%	30.4%	37.5%	30.0%	29.1%	36.8%	11.0%	40.0%	31.2%
Import waste	Mechanical Recycling	6.6%	14.2%	13.2%	12.4%	12.4%	39.5%	0.0%	0.0%	52.4%
Mechanical Recycling	Incineration	20.9%	38.1%	39.4%	44.8%	36.9%	37.1%	37.1%	37.1%	34.4%
Chemical Recycling	Incineration	0.0%	0.0%	0.0%	0.0%	0.0%	17.7%	0.0%	0.0%	0.0%
Mechanical Recycling	Landfill	2.4%	4.4%	4.6%	5.2%	4.3%	4.9%	4.9%	4.9%	4.6%
Chemical Recycling	Landfill	17.0%	17.0%	17.0%	17.0%	17.0%	2.3%	0.0%	0.0%	17.0%
Mechanical Recycling	Recyclates	76.6%	57.5%	56.0%	60.0%	70.8%	58.0%	59.1%	58.0%	61.1%
Chemical Recycling	Recyclates	83.0%	83.0%	83.0%	83.0%	83.0%	80.0%	0.0%	0.0%	83.0%
Recyclates	Packaging sector	18.6%	1.4%	0.0%	0.0%	22.8%	24.0%	24.0%	24.0%	30.4%

FROM	TO	P	C	T	E	A	TEX	F	H	O
Recyclates	Building sector	18.6%	92.8%	4.7%	22.8%	18.5%	46.0%	46.0%	46.0%	40.7%
Recyclates	Transport sector	3.6%	0.0%	45.2%	39.0%	0.0%	3.0%	3.0%	3.0%	3.0%
Recyclates	EEE sector	1.3%	0.0%	0.0%	11.4%	0.0%	2.0%	2.0%	2.0%	1.5%
Recyclates	Agriculture sector	0.0%	0.0%	0.0%	0.0%	40.4%	13.0%	13.0%	0.0%	13.0%
Recyclates	Textiles sector	0.0%	0.0%	0.0%	0.0%	0.0%	12.0%	0.0%	0.0%	0.0%
Recyclates	Other sector	58.0%	5.8%	50.1%	26.8%	18.2%	0.0%	12.0%	12.0%	11.4%
Recyclates	Export recyclates	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%
Incineration	Losses Incineration	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Losses Incineration	Microplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Microplastics	Water	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Microplastics	Soil	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Incineration	Landfill	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%
Landfill	Losses Landfill	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%
Losses Landfill	Microplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Microplastics	Water	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Microplastics	Soil	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Recycled polymers	Manufacturing	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%

Source: JRC Modelling. Note: P = Packaging; C = Construction, T = Transport, E = Electronic, A = Agriculture, TEX = Textiles, H = Healthcare, F = Fishing, O = Other

1.4. Polymers-specific assumptions

The polymers-specific MFAs were built leveraging the approach described in Section 2.4.2. This approach adopts the sector-specific polymers shares at the production level retrieved from Plastics Europe (2024). In Table 7 the fossil-/bio-based sector-specific polymer shares are provided. The details related to biopolymers were derived from Renewable carbon (2023) and allocated to each sector under scrutiny via data from EuRic (2020). Differently from the 2019 MFA, this study introduced bio-based polymers, specifically targeting those polymers being the majors' contributors in the EU bio-based market: bio-PP (13%), bio-PUR (19%), and CA (19%) (as indicated by Renewable carbon, 2023).

Table 7. Plastic polymers share per sector. Possible rounding effects may be present in the data.

Polymers	P	C	T	E	A	TEX	H	F	O
LDPE	29.4%	4.3%	3.6%	8.0%	33.8%	0.0%	0.8%	1.5%	11.1%
HDPE	18.0%	14.0%	7.1%	4.8%	2.8%	0.0%	0.8%	1.5%	7.9%
PP	23.4%	7.6%	19.9%	14.1%	35.2%	5.5%	47.2%	81.8%	20.5%
PS	3.0%	3.4%	0.2%	4.8%	0.0%	0.0%	0.0%	0.0%	2.7%
EPS	1.4%	13.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
PVC	1.9%	31.9%	3.1%	3.8%	8.5%	0.0%	0.0%	0.0%	4.0%
PET	19.4%	0.0%	0.0%	1.9%	0.0%	51.8%	1.1%	0.0%	1.8%
PUR	0.0%	1.9%	5.2%	5.4%	0.0%	0.0%	47.2%	0.0%	2.1%
ABS	0.0%	0.7%	1.2%	0.6%	0.0%	5.0%	0.0%	0.0%	4.3%
PMMA	0.3%	0.4%	6.9%	6.4%	0.0%	12.9%	2.8%	3.1%	2.6%
PA	0.0%	1.7%	4.4%	5.9%	0.0%	0.0%	0.0%	9.0%	0.5%
PC	1.4%	9.9%	34.4%	34.6%	19.7%	19.5%	0.0%	0.0%	23.6%
Other polymers	0.3%	10.8%	12.6%	9.3%	0.0%	0.0%	0.0%	3.1%	18.5%
bio-PP	0.3%	0.0%	0.3%	0.1%	0.0%	1.0%	0.0%	0.0%	0.1%
bio-PUR	0.3%	0.0%	0.3%	0.1%	0.0%	1.0%	0.0%	0.0%	0.1%
CA	0.2%	0.0%	0.2%	0.0%	0.0%	0.7%	0.0%	0.0%	0.1%
Other biopolymers	0.7%	0.1%	0.7%	0.2%	0.0%	2.6%	0.0%	0.0%	0.2%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: JRC Modelling. Note: P= Packaging; C= Construction, T= Transport, E= Electronic, A= Agriculture, TEX= Clothing and textiles, H= Healthcare, F= Fishing, O= Other, LDPE= Low-density polyethylene, HDPE= High-density polyethylene, PP= Polypropylene, PS= Polystyrene, EPS= Expanded Polystyrene, PVC= Polyvinyl Chloride, PET= Polyethylene terephthalate, PUR= Polyurethane, ABS= Acrylonitrile Butadiene Styrene, PMMA= Polymethyl methacrylate, PA= Polyamide, PC= Polycarbonates, bio-PP= bio-Polypropylene, bio-PUR= bio-Polyurethane, CA= Cellulose acetate

When available, polymers-specific data were adopted in the present study to generated sector-specific TCs. This approach enabled a more precise coverage of the polymer-specific value chain flows.

Polymers-specific data were especially retrieved for the following stages:

- **Trade:** imports and exports of primary polymers by sector (as outlined in Section 2.4.1) were specifically mapped via a bottom-up approach using PRODCOM codes retrieved from Eurostat (2022). The PRODCOM codes were classified by polymer and then were mapped by sectors with data production from Plastics Europe (Plastics Europe, 2024; e.g. code 20162035 'expansible polystyrene, in primary forms' were classified as EPS and allocated by sectors following Table 7);

- **Waste collection** to map the total waste mixed or separately collected in the polymers-specific MFAs, the same approach as of the sector-specific analysis was adopted (Annex 1.2). The information retrievable from Antonopoulos et al. (2021) and Lase (2023) concerning polymers-specific waste collection was nonetheless scrutinized. Adopting the TCs for the waste collected (as a mixed/separate fraction) from Antonopoulos et al. (2021) in the case of Packaging and from Lase (2023) in the case of the Construction, Transport, Electronic and Agriculture sectors would generate different results compared to the sector-specific analysis. For instance, the TC of the separately collected waste in the case of Packaging for the sector-specific analysis (63%; Plastics Europe, 2024) would differ by around 25 percentage points from the one of the polymers-specific analysis (around 38% on average; Antonopoulos et al., 2021). In the case of Agriculture, Plastics Europe (2024) indicates a separate collection rate of 51%, compared to the 59% reported by Lase (2023) on average among the abovementioned polymers. Additionally, for Electronics, data of the sector-specific analysis suggested a datum for separately collection TC of around 50% (Plastics Europe, 2024), differently from the average polymers-specific separately collection TC of around 37% from Lase (2023).
  In the case of the sector-specific analysis, the total quantity of plastic waste separately collected and sent to (mechanical) recycling facilities was mostly derived from Plastics Europe (2024). Such flow was revised in the case of the polymers-specific analysis, leveraging where available granular and polymers-specific details on separate waste collection amounts and waste (via key sources such as Antonopoulos et al., 2021 and Lase, 2023). Differences in the polymers-specific findings compared to sector-specific ones were highlighted via the identification of a dedicated 'unknown' flow (Section 2.2.2), capturing the gap between the two results when the two methodological approaches are applied (typically with sector-specific estimates being lower than sector-specific ones). In the case of Construction, the TC for separately collected waste sent to (mechanical) recycling was modelled via Plastics Europe (2024), as detailed in Annex 1.3. Notably, a difference in the total amounts for this stream and sector was identified when comparing polymers-specific data with sectors-specific ones (i.e., delta of around +0.4 Mt between polymers-specific data from Lase (2023) and sectors-specific data from Plastics Europe, 2024). This difference was highlighted as reflecting the potential variation in total recyclates generation in the EU, depending on whether a sector-specific or polymer-specific approach is applied;

- **Recycling:** specific assumptions were employed differently for mechanical and chemical treatments as outlined hereafter;

  - **Mechanical recycling**: the modelling approach for mechanical recycling efficiencies follows the method described in Annex 1.3. Mechanical recycling: In the case of the Packaging sector, mechanical recycling efficiencies and the fate associated to recycling residues to either incineration and landfill were mapped from Antonopoulos et al. (2021; i.e., LDPE, HDPE, PET and PVC) and Lase (2023; i.e., EPS). For the Building, Transport, Agriculture and Electronic sectors, the polymer-specific mechanical recycling efficiencies were retrieved by Lase (2023; HDPE, EPS, PVC, PP, PS, ABS). For the remaining sectors (namely: Textiles, Fishing and Other), polymer-specific TCs were instead calculated as an average recycling efficiency per polymer, based on the sectors analyzed by Lase (2023);

  - **Chemical recycling**: In the case of Packaging sector, chemical recycling efficiencies were retrieved from Lase (2023; i.e., LDPE, HDPE, EPS). For the remaining scrutinized sectors, polymer-specific TCs were based on sector-specific MFA models;

- **Compostable waste:** due to lack of specific data associated to the polymer-specific quantity of compostable plastics sent to composting facilities, it was assumed that solely 50% of cellulose acetate and 'other biopolymers' were properly collected and composted (following the same logic described in Section 1.3).

As an example, the complete set of TCs employed to map polymer-specific flows in the Packaging sector are presented in Table 8.

Table 8. Summary of the Transfer coefficients (TCs) adopted for modelling plastic material flows at polymers level in the Packaging sector in the EU-27 for the year 2022. Possible rounding effects may be present in the data.

FROM	TO	LDPE	HDPE	PP	PS	EPS	PVC	PET	PUR	ABS	PA	PMMA	PC	Other fossil-based	bio-PP	bio-PUR	CA	Other bio-based
Polymers production	Virgin polymers	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Polymers production	Bioplastics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%
Import polymers	Demand	15.8%	3.8%	16.2%	0.1%	0.1%	0.6%	57.0%	0.0%	0.0%	0.1%	0.0%	0.0%	6.4%	0.0%	0.0%	0.0%	0.0%
Demand	Export polymers	4.6%	5.2%	14.9%	0.5%	0.1%	2.0%	59.3%	0.1%	0.0%	0.1%	0.0%	0.0%	13.1%	0.0%	0.0%	0.0%	0.0%
Manufacturing	Consumption	90.6%	90.6%	90.6%	90.6%	90.6%	90.6%	90.6%	90.6%	90.6%	90.6%	90.6%	90.6%	90.6%	99.9%	99.9%	99.9%	99.9%
Manufacturing	Export Products	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%	0.0%	11.2%	11.2%	11.2%	11.2%
Import Products	Consumption	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	0.0%	10.3%	10.3%	10.3%	10.3%
Manufacturing	Pre-consumer waste	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	0.0%	0.0%	0.0%	0.0%
Pre-consumer waste	Separated waste	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Manufacturing	Losses manufacturin g	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Losses manufacturing	Microplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Losses manufacturing	Macroplastics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Microplastics	Water	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%

FROM	TO	LDPE	HDPE	PP	PS	EPS	PVC	PET	PUR	ABS	PA	PMMA	PC	Other fossil-based	bio-PP	bio-PUR	CA	Other bio-based
Microplastics	Soil	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%	69.0%
Microplastics	Recollected	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%
Macroplastics	Water	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%	26.7%
Macroplastics	Soil	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%	59.3%
Macroplastics	Recollected	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%
Consumption	Waste generated	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%	92.6%
Consumption	Losses consumption	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%
Losses consumption	Microplastics	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Losses consumption	Macroplastics	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Microplastics	Water	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Microplastics	Soil	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Microplastics	Recollected	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Water	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Macroplastics	Soil	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%
Macroplastics	Recollected	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%
Waste collected	Prep. To Reuse and Reuse	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Consumption	Stock	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%
Waste generated	Export waste	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%

FROM	TO	LDPE	HDPE	PP	PS	EPS	PVC	PET	PUR	ABS	PA	PMMA	PC	Other fossil-based	bio-PP	bio-PUR	CA	Other bio-based
Waste generated	Waste collected	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%	89.8%
Waste collected	Mixed waste	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	36.6%	18.4%	18.4%
Waste collected	Separated waste	63.4%	63.4%	63.4%	63.4%	63.4%	63.4%	63.4%	63.4%	63.4%	63.4%	63.4%	63.4%	63.4%	62.9%	62.9%	31.6%	31.6%
Waste collected	Composting waste	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%
Waste generated	Losses waste	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Losses waste	Microplastics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Losses waste	Macroplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Microplastics	Water	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Microplastics	Soil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Microplastics	Recollected	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Water	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%
Macroplastics	Soil	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%
Macroplastics	Recollected	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%
Mismanaged Waste	Recollected	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%	21.9%
Waste generated	Mismanaged Waste	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%
Mismanaged Waste	Losses mismanaged	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%
Losses mismanaged	Microplastics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

FROM	TO	LDPE	HDPE	PP	PS	EPS	PVC	PET	PUR	ABS	PA	PMMA	PC	Other fossil-based	bio-PP	bio-PUR	CA	Other bio-based
Losses mismanaged	Macroplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Microplastics	Water	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Water	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%
Microplastics	Soil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Soil	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%	56.2%
Microplastics	Recollected	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Macroplastics	Recollected	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%	28.1%
Mismanaged Waste	Unsanitary Landfill	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%	30.7%
Mismanaged Waste	Open Dump	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%	27.9%
Mixed waste	Mechanical Recycling	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed waste	Chemical Recycling	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed waste	Incineration	63.1%	63.1%	63.1%	63.1%	63.1%	63.1%	63.1%	63.1%	63.1%	63.1%	63.2%	63.2%	63.2%	63.2%	63.2%	63.2%	63.2%
Mixed waste	Landfill	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%	36.8%
Separated waste	Mechanical Recycling	47.6%	78.1%	52.0%	48.0%	48.0%	63.2%	77.4%	59.1%	59.1%	59.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Separated waste	Chemical Recycling	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Separated waste	Incineration	44.0%	18.0%	40.2%	43.6%	43.6%	31.9%	18.6%	34.2%	34.2%	34.2%	85.1%	85.1%	85.1%	85.1%	85.1%	85.1%	85.1%
Separated waste	Landfill	7.7%	3.2%	7.1%	7.7%	7.7%	4.2%	3.3%	6.0%	6.0%	6.0%	14.9%	14.9%	14.9%	14.9%	14.9%	14.9%	14.9%

FROM	TO	LDPE	HDPE	PP	PS	EPS	PVC	PET	PUR	ABS	PA	PMMA	PC	Other fossil-based	bio-PP	bio-PUR	CA	Other bio-based
Import waste	Mechanical Recycling	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%
Mechanical Recycling	Incineration	26.0%	10.8%	30.5%	30.9%	30.5%	17.5%	16.5%	30.5%	20.9%	89.6%	20.9%	20.9%	20.9%	20.9%	20.9%	20.9%	20.9%
Chemical Recycling	Incineration	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mechanical Recycling	Landfill	3.0%	1.2%	3.5%	3.6%	3.5%	2.0%	2.5%	3.5%	2.4%	10.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%
Chemical Recycling	Landfill	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%
Mechanical Recycling	Recyclates	71.0%	88.0%	66.0%	65.5%	66.0%	80.4%	81.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	76.6%	76.6%	76.6%	76.6%
Chemical Recycling	Recyclates	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%	83.0%
Recyclates	Packaging sector	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%
Recyclates	Building sector	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%	18.6%
Recyclates	Transport sector	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%
Recyclates	EEE sector	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%
Recyclates	Agriculture sector	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Recyclates	Textiles sector	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Recyclates	Other sector	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%	58.0%
Recyclates	Export recyclates	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%

FROM	TO	LDPE	HDPE	PP	PS	EPS	PVC	PET	PUR	ABS	PA	PMMA	PC	Other fossil-based	bio-PP	bio-PUR	CA	Other bio-based
Incineration	Losses Incineration	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Losses Incineration	Microplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Microplastics	Water	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Microplastics	Soil	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Incineration	Landfill	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%
Landfill	Losses Landfill	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%
Losses Landfill	Microplastics	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Microplastics	Water	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Microplastics	Soil	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Recycled polymers	Manufacturin g	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%	87.2%

Source: JRC Modelling. Note: P = Packaging; C = Construction, T = Transport, E = Electronic, A = Agriculture, TEX = Clothing and textiles, H = Healthcare, F = Fishing, O = Other, LDPE = Low-density polyethylene, HDPE = High-density polyethylene, PP = Polypropylene, PS = Polystyrene, EPS = Expanded Polystyrene, PVC = Polyvinyl Chloride, PET = Polyethylene terephthalate, PUR = Polyurethane, ABS = Acrylonitrile Butadiene Styrene, PMMA = Polymethyl methacrylate, PA = Polyamide, PC = Polycarbonates, bio-PP = bio-Polypropylene, bio-PUR = bio-Polyurethane, CA = Cellulose acetate.

Annex 2

2.1. Key life cycle assessment information

A description of the life cycle inventory employed for each life cycle stage of the plastic value chain is presented hereafter. As mentioned in the methodological section (Section 2.5), the entirety of the mass entering a given node (input data based on the sector-specific findings) was accounted in the LCA analysis and multiplied by its specific impacts for each life cycle under scrutiny (all datasets included in the analysis are listed in Annex2.2). For instance, in the case of plastic waste entering recycling facilities, the total mass of plastic estimated from the sector-specific models was considered. Polymers-specific impacts/credits were associated to this mass proportionally to each sector-specific polymers (considering when/if a polymer is recycled and according to the available dataset information). Further details are provided in this Annex with regard to each life cycle stage LCA calculations. The transportation of plastics between life cycle stages was modelled and estimated using transportation-specific datasets which are also included in Annex 2.2(these include for instance impacts of transportation via truck, train or barge and varying according to the life cycle stage under examination). An overview of the modelling approach for each life cycle stage is presented hereafter:

Production: the polymer-specific contributions of the plastic production of each sector were calculated coupling the various polymers shares retrieved from the MFA model (Annex 1.4) with the virgin polymers production impacts (datasets listed in the Annex 2.2). To model the production of 'Other polymers' category the ecoinvent dataset "Acrylic varnish, without water, in 87.5% solution state {RER}| acrylic varnish production, product in 87.5% solution state | Cut-off, U" was employed. The contributions of each polymer per each sector is illustrated in Table 10. The current analysis excludes the impacts associated with bio-based plastics production, as their volumes is negligible compared to the fossil-based counterparts (1.1% of the total production; Section 3.1).

Table 9. Plastic polymers' share per sector employed in the LCA analysis.

Polymers	P	C	T	E	A	TEX	H	F	O
LDPE	29.8%	4.3%	3.6%	8.0%	33.8%	0.0%	0.8%	1.5%	11.1%
HDPE	18.3%	14.1%	7.2%	4.8%	2.8%	0.0%	0.8%	1.5%	7.9%
PP	23.7%	7.7%	20.2%	14.1%	35.2%	5.8%	47.2%	81.8%	20.6%
PS	3.0%	3.4%	0.2%	4.8%	0.0%	0.0%	0.0%	0.0%	2.7%
EPS	1.4%	13.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
PVC	1.9%	32.0%	3.1%	3.9%	8.5%	0.0%	0.0%	0.0%	4.1%
PET	19.7%	0.0%	0.0%	1.9%	0.0%	54.8%	1.1%	0.0%	1.8%
PUR	0.3%	10.8%	12.8%	9.3%	0.0%	0.0%	0.0%	3.1%	18.6%
ABS	0.0%	1.9%	5.3%	5.5%	0.0%	0.0%	47.2%	0.0%	2.1%
PA	0.3%	0.5%	7.0%	6.4%	0.0%	13.6%	2.8%	3.1%	2.6%
Other polymers	1.5%	12.3%	40.5%	41.2%	19.7%	25.8%	0.0%	9.0%	28.6%

Source: JRC Modelling

Manufacturing: the assessment of the emissions related to plastic product manufacturing was based on key industrial processes typically employed in the EU. The identification of the sector-specific manufacturing processes followed the approach described in the Supplementary Material (SM2) of Amadei et al. (2025). In particular, emissions related to injection moulding (IM), extrusion of plastic pipes (Ep), and extrusion of plastic films (Ef) were included as proxies to map the life cycle impacts of manufacturing among the various sectors (Amadei et al., 2025). To each sector, the manufacturing impacts were allocated as follows (based on Amadei et al., 2025): Packaging: 100% IM; Construction: 39% IM, 31% Ep, 31% Ef; Agriculture: 39% IM, 31% Ep, 31% Ef; Transport: 45% IM, 28% Ep, 28% Ef; Electronics: 94% IM, 3% Ep, 3% Ef; Clothing and textiles: 0% IM, 50% Ep, 50% Ef; Fishing: 0% IM, 50% Ep, 50% Ef; Healthcare: 61% IM, 19.5% Ep, 19.5% Ef; 'Other': 61% IM, 19.5% Ep, 19.5% Ef. Other technologies, such as for instance blow moulding, compression moulding, and rotomoulding, (also used in the EU to produce plastic products) were not included in the analysis due to (i) lack of corresponding ecoinvent datasets, and (ii) the fact that injection moulding and extrusion are widely and commonly used in various sectors and products (e.g., small to medium-sized components in automotives, consumer goods, packaging and packaging films, construction elements such as pipes and profiles, etc.). To further refine the analysis, a more detailed breakdown of manufacturing technologies by market and sector could be explored. However, this would necessitate the availability of specific and robust market data, which is currently lacking in the existing literature. In this life cycle stage, the impacts associated to pre-consumer waste were also considered and modelled following the assumptions related to the sector-specific MFA (Section 3.1). All pre-consumer waste was assumed to be separately collected and managed according to the waste separately collected. The impacts related to pre-consumer waste included the impacts associated with waste transportations, following the approach retrieved from SM7 of Amadei et al. (2025).

Consumption (retail and use): the environmental impacts related to this life cycle stage included solely the transportation of plastic goods by consumers. Such impacts were modelled following the assumptions by SM7 of Amadei et al., 2025. For certain sectors (e.g. Packaging, Agriculture, Electronic, Textiles, Fishing, Healthcare, and 'Other'), it was assumed that 62% of transportation occurs by van over a distance of 5 km (Nessi et al., 2021a,b). The remaining 38% was assumed to take place on foot or by bike, resulting in no allocated environmental impacts (Nessi et al., 2021a,b). Notably, no impacts were assumed to be associated to the transportation of products for the Construction and Transport sectors, since no direct transportation occurs for their purchase by final consumers.

Reuse: the analysis of this life cycle stages focused on the assessment of the credits and impacts for the Transport and the Textiles sectors. The assessment of impacts and credits for this life cycle stage in the case of other sectors such as Electronics were not mapped in the present study (due to a lack of available specific data), and could be subject of future revision of the analyses. In the case of the plastic products/components included in the Transport and Textiles sectors, it was assumed that plastics were reused only once throughout their entire life cycle.
With regard to the Transport sector, the assumptions on impacts and credits were based on Amadei et al, (2025), focused on an average vehicle and considered:

- Impacts: transportation of 55% of the total used vehicles within the EU (i.e. reused within the EU territory), with an average distance of 1500 km by lorry (dataset 'Transport, freight, lorry >32 metric ton, EURO4 {GLO}| market for | Cut-off, U'). The remaining 45% of the total used vehicles were exported extra-EU (i.e. reused outside the EU territory), involving an assumed trip from Brussels to Nairobi (10,385 km) via train, barge and lorry. Further, the impacts associated with the maintenance of used vehicles were considered and assumed to account for 20% of the total plastic mass (Optimat, 2013).
- Credits: reusing 1 kg of plastics avoids the impacts of primary plastics manufacturing, with credits applied for the non-exported fraction, considering a depreciation effect of 40% due to the reduced mileage of used vehicles. Credits only cover the non-maintained share of plastics

in the vehicle (80%), and were calculated considering the avoided impacts of production in the Transport sector (i.e. considering the production impacts of the Transport sector as modelled in the present study).

With regard to the Textiles sector, the assumptions on impacts and credits were based on Amadei et al, (2025), focused on an average t-shirt and considered:

- Impacts: once discarded, clothes need to be washed before reuse. It was considered that 20g of dishwasher detergents are needed per wash cycle and the associated dishwasher life cycle impacts were estimated using the Consumption Footprint basket of product indicator for Household Goods (Castellani et al., 2019). On top of dishwasher needs, the impacts related to 35L of water consumption for washing were included, following water needs estimations reported by McNamara (2013). Washing also requires 15.4 kWh of electricity, whose impacts were estimated using European low-voltage electricity production (inventory data calculated from McNamara, 2013). On top of washing, impacts associated with transportation for the reuse step were also estimated using EURO4 lorries, covering a total distance of 130 km (Amadei et al., 2025). Additionally, the impacts of transporting reusable textiles to the consumption stage were considered, with a distance of 200 km via EURO4 lorries of medium size (16-32 metric tons; Amadei et al., 2025).
- Credits: to map credits the dataset used was '1 kg Textile, non-woven polyester {RoW}| textile production, non woven polyester, needle punched | Cut-off, U'. However, in this sector the modelling approach to map credits could be further developed to explore the interconnections between recycled textile flows and the materials or products they replace, incorporating the latest insights from literature.

Waste collection and management: the various assumptions employed for this life cycle stage are based on the SM7 of Amadei et al. (2025) and Nessi et al. (2021a,b). In particular, the impacts associated to post-consumer waste collection (the sector-specific fraction of mixed or separately collected waste; Sector 3.1) were modelled considering various means of waste disposal/collection (e.g. kerbside collection, streets containers, etc.). Details of this modelling are provided in Table 10. The transportation of the collected waste to the various end-of-life waste treatment facilities (i.e. incinerators, landfills, recycling facilities) was also accounted (assuming EURO4 >32metric ton lorry transportation for 50km; Annex 2.2).

Table 10. Waste collection modelling approach (each transportation means corresponds to a ecoinvent dataset – Section 2.2).

Type of transport	To recycling facilities	To incineration facilities	To landfilling facilities
Kerbside collection	59% of total transport impacts, using medium/large-sized trucks (16-32 metric ton) with a total distance of 49 km	71% of total transport impacts, using medium/large-sized trucks (16-32 metric ton) with a distance of 15.5 km	71% of total transport impacts, using medium/large-sized trucks (16-32 metric ton) with a distance of 15.5 km
Street containers	9% of total transport impacts, using medium/large-sized trucks (16-32 metric ton) with a distance of 48 km	29% of total transport impacts, using medium/large-sized trucks (16-32 metric ton) with a distance of 7.5 km	29% of total transport impacts, using medium/large-sized trucks (16-32 metric ton) with a distance of 7.5 km
Drop-off areas	12% of total transport impacts, using vans (light commercial vehicles) with a distance of 2.5 km	-	-

Source: Amadei et al. (2025), based on Nessi et al. (2021a,b)

Waste management: this life cycle stage entails the impacts (and credits) associated with waste recycling, incineration and landfill.

- **Recycling**: Impacts and credits were mapped for the following subset of fossil-based polymers sent to recycling (Section 3.2): LDPE, HDPE, PP, PS, EPS, PVC, PET, PUR and ABS. When no specific recycling impacts were available, proxies were selected (Table 11). These polymers altogether covered more than 80 % of the total production of plastics in the EU. Further, findings from Antonopoulos et al. (2021) and Euric (2020) illustrated how typical recycling facilities in the EU manage LDPE, PP, PS and PVC on top of PET and HDPE. In the case of certain other polymers, despite available mass flow data concerning their recycling, the lack of specific dataset hindered the possibility of mapping the associated impacts/credits. For instance, the MFA study underlined that a certain quantity of PA polymer is recycled in the electronic sectors; however, no specific impacts/credits were associated to PA recycling due to lack of proper datasets suitable for the mapping PA recycling impacts/credits. Similarly, PMMA recycling impacts/credits were excluded. This assumption should be considered when analysing impacts and credits presented of recycling in this study, and potentially improved in the future to account for the recycling of other polymers. As part of the recycling stage, the environmental pressures associated with plastic residues from recycling were also evaluated and accounted according to their specific fate (described in the following paragraph for incineration and landfilling). The recycling processes examined in this study were limited to mechanical recycling activities (excluding chemical recycling, as a consequence of missing datasets for their emissions estimates). Transportation impacts of recycled plastics to manufacturing industries were also accounted. Table 11 provides a detailed description on the modelling of impacts/credits for each polymer under scrutiny. To model impacts and credits described in Table 11, the polymer-specific recycling efficiencies for each sector are crucial. Together with these efficiencies, it is necessary to map the fate of the polymer-specific recycling residues within each sector. All these parameters are summarized in Table 12and were calculated based on the polymer-specific MFAs findings (Section 3.2). Notably, credits (mapped according to the approach described in Table 11) were accounted solely for the actual recycled fraction of each polymer (i.e. considering its recycling efficiency).

Table 11. Modelling approach for plastic recycling impacts and credits at the polymer level (associated datasets are listed in Annex 2.2).

Polymer	Impacts	Credits
HDPE	Pre-treatment and recycling process (Amadei et al.,2025). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	HDPE primary production
LDPE	Pre-treatment and recycling process (proxy based on HDPE). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	LDPE primary production
PET	Pre-treatment and recycling process (Amadei et al.,2025). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	PET primary production
PP	Pre-treatment and recycling process (proxy based on PET). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	PP primary production
PS	Pre-treatment and recycling process (proxy based on EPS). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	PS primary production
EPS	Pre-treatment and recycling process ('Polystyrene foam slab {CH}| production, 100% recycled | Cut-off, U' dataset). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	EPS primary production
PVC	Pre-treatment and recycling process (proxy based on PET). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	PVC primary production
PUR	Pre-treatment and recycling process (median between HDPE and EPS processes). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	PUR primary production
ABS	Pre-treatment and recycling process (proxy based on HDPE). Transport of non-exported recyclates to manufacturing industries (by barge, lorry>32t and train; Amadei et al.,2025).	ABS primary production

Source: JRC Modelling and Amadei et al. (2025)

Table 12. Details on the polymer-specific recycling efficiencies and the specific recycling residues fate for each sector. Note: "R_Eff" = Recycling efficiency; "Res_inc" = Recycling residues to incineration with energy recovery; "Res_lan" = Recycling residues to landfilling; sector-specific acronyms are in explained in Table 3.

Sector	HDPE	LDPE	PET	PP	PS	EPS	PVC	PUR	ABS
P	R_Eff: 88 Res_inc: 11 Res_lan: 1	R_Eff: 71 Res_inc: 26 Res_lan: 3	R_Eff: 81 Res_inc: 17 Res_lan: 2	R_Eff: 66 Res_inc: 31 Res_lan: 3	R_Eff: 66 Res_inc: 31 Res_lan: 3	R_Eff: 33 Res_inc: 60 Res_lan: 7	R_Eff: 80 Res_inc: 18 Res_lan: 2	R_Eff: 33 Res_inc: 60 Res_lan: 7	R_Eff: - Res_inc: - Res_lan: -
C	R_Eff: 70 Res_inc: 27 Res_lan: 3	R_Eff: 70 Res_inc: 27 Res_lan: 3	R_Eff: - Res_inc: - Res_lan: -	R_Eff: 79 Res_inc: 19 Res_lan: 2	R_Eff: 79 Res_inc: 19 Res_lan: 2	R_Eff: 70 Res_inc: 27 Res_lan: 3	R_Eff: 55 Res_inc: 40 Res_lan: 5	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -
T	R_Eff: 72 Res_inc: 25 Res_lan: 3	R_Eff: 72 Res_inc: 25 Res_lan: 3	R_Eff: - Res_inc: - Res_lan: -	R_Eff: 56 Res_inc: 39 Res_lan: 5	R_Eff: 72 Res_inc: 25 Res_lan: 3	R_Eff: - Res_inc: - Res_lan: -	R_Eff: 72 Res_inc: 25 Res_lan: 3	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -
E	R_Eff: 50 Res_inc: 45 Res_lan: 5	R_Eff: 50 Res_inc: 45 Res_lan: 5	R_Eff: 50 Res_inc: 45 Res_lan: 5	R_Eff: 60 Res_inc: 36 Res_lan: 4	R_Eff: 60 Res_inc: 36 Res_lan: 4	R_Eff: - Res_inc: - Res_lan: -	R_Eff: 50 Res_inc: 45 Res_lan: 5	R_Eff: 50 Res_inc: 45 Res_lan: 5	R_Eff: 60 Res_inc: 36 Res_lan: 4
A	R_Eff: 59 Res_inc: 37 Res_lan: 4	R_Eff: 59 Res_inc: 37 Res_lan: 4	R_Eff: - Res_inc: - Res_lan: -	R_Eff: 59 Res_inc: 37 Res_lan: 4	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: 59 Res_inc: 37 Res_lan: 4	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -
TEX	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: 80 Res_inc: 18 Res_lan: 2	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -
F	R_Eff: 58 Res_inc: 37 Res_lan: 5	R_Eff: 58 Res_inc: 37 Res_lan: 5	R_Eff: 58 Res_inc: 37 Res_lan: 5	R_Eff: 58 Res_inc: 37 Res_lan: 5	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: 58 Res_inc: 37 Res_lan: 5
H	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -	R_Eff: - Res_inc: - Res_lan: -
O	R_Eff: 73 Res_inc: 24 Res_lan: 3	R_Eff: 73 Res_inc: 24 Res_lan: 3	R_Eff: 73 Res_inc: 24 Res_lan: 3	R_Eff: 73 Res_inc: 24 Res_lan: 3	R_Eff: 73 Res_inc: 24 Res_lan: 3	R_Eff: 73 Res_inc: 24 Res_lan: 3	R_Eff: 73 Res_inc: 24 Res_lan: 3	R_Eff: 73 Res_inc: 24 Res_lan: 3	R_Eff: 73 Res_inc: 24 Res_lan: 3

Source: JRC Modelling

- **Incineration**: the specific emissions profiles associated with the incineration of different plastic polymers were captured by employing specialized ecoinvent datasets (Annex 2.2). These datasets also encompass the environmental impacts associated with the disposal of incineration residues in landfills. The energy requirements for shredding plastic waste are modelled according to Garcia-Gutierrez et al. (2023), for all polymer-specific incineration impacts and added to the ecoinvent datasets. As a consequence of waste incineration, energy and heat are recovered. To capture such credits, energy and heat recovery efficiencies were calculated using gross efficiency rates for electricity (13.7 %) and heat (31.8 %), as estimated in Amadei et al. (2025), according to Nessi et al. (2021a, b). Further, polymer-specific lower heating values (LHV) derived from Garcia-Gutierrez et al. (2023) were also considered to calculate the polymer-specific credits (detailed in Table 13). Impacts related to 'waste plastic mixture incineration' were used to map incineration of PA, ABS, and 'Other fossil-based polymers' due to missing specific ecoinvent datasets for the plastic waste incineration of these polymers. Table 13 provides an overview of the polymer-specific models, outlining their associated impacts and credits.

Table 13. A detailed description of the modelling approach for impacts and credits associated with plastic incineration with energy recovery at the polymer level (associated datasets are listed in Annex 2.2).

Polymer	Lower Heating Value [MJ/kg]	Impacts	Credits
HDPE	41.5	Shredding and incineration with energy recovery	Electricity mix and thermal mix substitution (based on incinerator efficiency and HDPE LHV)
LDPE	27.2	Shredding and incineration with energy recovery	Electricity mix and thermal mix substitution (based on incinerator efficiency and LDPE LHV)
PET	23.2	Shredding and incineration with energy recovery	Electricity mix and thermal mix substitution (based on incinerator efficiency and PET LHV)
PP	41.9	Shredding and incineration with energy recovery	Electricity mix and thermal mix substitution (based on incinerator efficiency and PP LHV)
PS	38.0	Shredding and incineration with energy recovery	Electricity mix and thermal mix substitution (based on incinerator efficiency and PS LHV)
PVC	21.6	Shredding and incineration with energy recovery	Electricity mix and thermal mix substitution (based on incinerator efficiency and PVC LHV)
EPS	32.3	Shredding and incineration with energy recovery	Electricity mix and thermal mix substitution (based on incinerator efficiency and EPS LHV)
PUR	30.9	Shredding and incineration with energy recovery	Electricity mix and thermal mix substitution (based on incinerator efficiency and PUR LHV)
ABS	32.0	Shredding and incineration with energy recovery (based on plastic waste mixture)	Electricity mix and thermal mix substitution (based on incinerator efficiency and ABS LHV)
PA	39.0	Shredding and incineration with energy recovery (based on plastic waste mixture)	Electricity mix and thermal mix substitution (based on incinerator efficiency and PA LHV)
Other	32.06 (estimated as average)	Shredding and incineration with energy recovery (based on plastic waste mixture)	Electricity mix and thermal mix substitution (based on incinerator efficiency and 'Other' LHV)

Source: JRC Modelling and Amadei et al. (2025)

- **Landfill**: the environmental impacts of plastic landfilling in each sector were estimated using a general dataset reported in Annex 2.2 (i.e. general emission profile of waste plastic landfilling).

Mismanaged waste: the impacts related to mismanaged waste account for the quantity of mismanaged plastics that could be exported outside of the EU and its associated potential fate. Impacts related to losses of plastics in the environment were excluded from the LCA analysis, as detailed in Section 2.5. Concerning the mismanaged plastic waste assumed to be exported outside the EU, the potential fate of these plastic flows was retrieved from Systemiq (2024). Details on the modelling for plastic waste mismanaged are provided in Table 14.

Table 14. Fates considered for plastic waste mismanagement (no impacts were associated to the fraction of mismanaged waste ultimately lost).

Sector	Unsanitary landfill	Open dump	Lost	Recollected
Packaging	31%	28%	20%	21%
Construction	39%	36%	25%	0%
Transport	31%	28%	20%	21%
Electronic	31%	28%	20%	21%
Agriculture	39%	36%	25%	0%
Textiles	39%	36%	25%	0%
Fishing	39%	36%	25%	0%
Healthcare	39%	36%	25%	0%
Other	31%	28%	20%	21%

Source: JRC Modelling and Systemiq (2024)

Trade: impacts of transportation and production/manufacturing were modelled for the plastic polymers/products/waste in the various life cycle stages are described. All trade flows captured in the MFA models, but not described in the below paragraphs were not covered in the LCA analysis to adhere with the selected functional unit.

- Primary plastics**:** to comply with the functional unit and system boundaries of the study, impacts associated with import of primary plastics were accounted, whilst impacts associated with export of primary plastic were not considered. Transportation of primary plastics was assumed to occur via transoceanic ship and lorry (distances and datasets (Annex 2.2) selection modelled according to SM8 of Amadei et al., 2025; and Nessi et al. 2021a,b). On top of transportation, the impacts related to the production of plastics occurring outside of the EU were captured. To do so, the approach described in SM8 of Amadei et al. (2025) was applied (analysing the most relevant countries responsible for exporting key polymers such as HDPE, LDPE, PET and PP; and calculating polymers' production impacts via replacing the EU energy/heat mix in the related polymers' production ecoinvent dataset with the energy/heat emissions profile of the identified exporting countries).

- Plastic products: to comply with the functional unit and system boundaries of the study, impacts associated with import of plastic products were accounted, whilst impacts associated with export of primary plastic were not considered. Transportation impacts of plastic products were modelled considering transoceanic ship and lorry (distances and datasets (Annex 2.2) modelled according to SM8 of Amadei et al., 2025). On top of transportation, the impacts related to the production of plastics occurring outside of the EU were captured (as described in the previous paragraph) plus the impacts associated with products manufacturing outside the EU, estimated considering the impacts associated with injection moulding ("Injection moulding {RoW}| processing | Cut-off, U") and extrusion ("Extrusion, plastic pipes {RoW}| extrusion, plastic pipes | Cut-off, U") with a 50% share each.

- Plastic waste: based on the modelling approach described in SM8 of Amadei et al., (2025), the countries receiving most of the plastic waste from EU were identified (e.g. Malaysia, Türkiye, Indonesia, etc.). Transportation impacts of plastic waste were modelled considering transoceanic ship and lorry (distances and datasets (Annex 2.2) modelled according to SM8 of Amadei et al., 2025 for the abovementioned receiving identified geographies). On top of transportation, the impacts related to the end-of-life management occurring outside of the EU were captured (according to the modelling approach described in SM8 of Amadei et al., 2025). In particular, these captured the end-of-life impacts of plastic waste management in Malaysia and Türkiye considering a 59%-41% share between the two countries (mostly occurring via landfills or unsanitary landfills).

2.2. Overview of employed life cycle datasets

Table 15 includes the list of datasets used for the LCA analysis (Section 3.4), with details on the life cycle stages in which each dataset was employed.

Table 15. Datasets employed in the life cycle assessment analysis of the plastic value chain.

Stage/Comment	ecoinvent dataset name
Trade and transportation	Transport, freight, lorry >32 metric ton, EURO4 {GLO}| market for | Cut-off, U
Trade and transportation	Transport, freight, sea, transoceanic ship {GLO}| market for | Cut-off, U
Trade and transportation	Transport, freight, lorry >32 metric ton, euro4 {RER}| market for transport, freight, lorry >32 metric ton, EURO4 | Cut-off, U
Trade and transportation	Transport, freight, inland waterways, barge tanker {RER}| market for transport, freight, inland waterways, barge tanker | Cut-off, U
Trade and transportation	Transport, freight train {RER}| market group for transport, freight train | Cut-off, U
Trade and transportation	Transport, freight, lorry 3.5-7.5 metric ton, euro4 {RER}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO4 | Cut-off, U
Trade and transportation	Transport, freight, lorry 16-32 metric ton, euro4 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U
Trade and transportation	Transport, freight, light commercial vehicle {RER}| market group for transport, freight, light commercial vehicle | Cut-off, U
Production, recycling credits	Polyethylene, low density, granulate {RER}| production | Cut-off, U
Production, recycling credits	Polyethylene, high density, granulate {RER}| production | Cut-off, U
Production, recycling credits	Polypropylene, granulate {RER}| production | Cut-off, U
Production, recycling credits	Polystyrene, general purpose {RER}| production | Cut-off, U
Production	Polystyrene, expandable {RER}| production | Cut-off, U
Production, recycling credits	Polyvinylchloride, suspension polymerised {RER}| polyvinylchloride production, suspension polymerisation | Cut-off, U
Production, recycling credits	Polyethylene terephthalate, granulate, amorphous {RER}| production | Cut-off, U
Production	Polyurethane, rigid foam {RER}| production | Cut-off, U
Production	Styrene-acrylonitrile copolymer {RER}| production | Cut-off, U
Production	Nylon 6 {RER}| production | Cut-off, U
Production	Polycarbonate {RER}| production | Cut-off, U
Production	Acrylic varnish, without water, in 87.5% solution state {RER}| acrylic varnish production, product in 87.5% solution state | Cut-off, U

Stage/Comment	ecoinvent dataset name
Manufacturing	Extrusion, plastic film {RER}| extrusion, plastic film | Cut-off, U
Manufacturing	Extrusion, plastic pipes {RER}| production | Cut-off, U
Manufacturing	Injection moulding {RER}| processing | Cut-off, U
Consumption	Transport, freight, light commercial vehicle {RER}| market group for transport, freight, light commercial vehicle | Cut-off, U
Reuse	Dishwasher detergents (life cycle impacts) - Castellani et al. (2019)
Reuse	Tap water, at user {Europe without Switzerland}| tap water production and supply | APOS, U
Reuse	Electricity, low voltage {RER}| market group for | Cut-off, U
Reuse	Textile, non-woven polyester {RoW}| textile production, non woven polyester, needle punched | Cut-off, U
Reuse	Passenger car maintenance {RER}| maintenance, passenger car | Cut-off, U
Recycling (modified to 1kg input)	Polyethylene, high density, granulate, recycled {Europe without Switzerland}| polyethylene production, high density, granulate, recycled | Cut-off, U
Recycling (modified to 1kg input)	Polyethylene terephthalate, granulate, amorphous, recycled {Europe without Switzerland}| polyethylene terephthalate production, granulate, amorphous, recycled | Cut-off, U
Recycling	Polystyrene foam slab {CH}| production, 100% recycled | Cut-off, U
Electricity mix	Electricity, high voltage {AT}| electricity production, hydro run-of-river | Cut-off, U
Electricity mix	Electricity, high voltage {BE}| electricity production, nuclear, pressure water reactor | Cut-off, U
Electricity mix	Electricity, high voltage {BG}| electricity production, lignite | Cut-off, U
Electricity mix	Electricity, high voltage {CZ}| heat and power co-generation, lignite | Cut-off, U
Electricity mix	Electricity, high voltage {DE}| electricity production, deep geothermal | Cut-off, U
Electricity mix	Electricity, high voltage {DE}| electricity production, hard coal | Cut-off, U
Electricity mix	Electricity, high voltage {DE}| electricity production, lignite | Cut-off, U
Electricity mix	Electricity, high voltage {DE}| electricity production, nuclear, pressure water reactor | Cut-off, U
Electricity mix	Electricity, high voltage {DE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U
Electricity mix	Electricity, high voltage {DE}| heat and power co-generation, biogas, gas engine| Cut-off, U
Electricity mix	Electricity, high voltage {DE}| heat and power co-generation, natural gas, converntional power plant, 100MW electrical | Cut-off, U
Electricity mix	Electricity, high voltage {DE}| heat and power co-generation, wood chips, 6667kW, state-of-the-art 2014| Cut-off, U

Stage/Comment	ecoinvent dataset name
Electricity mix	Electricity, high voltage {EE}| electricity production, oil | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| electricity production, hard coal | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| electricity production, hydro run-of-river | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| electricity production, nuclear, pressure water reactor | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| electricity production, oil | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| electricity production, solar thermal parabolic trough, 50 MW | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| electricity production, solar tower power plant, 20 MW | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| electricity production, wind, <1MW turbine, onshore | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U
Electricity mix	Electricity, high voltage {ES}| heat and power co-generation, natural gas, combined cycle power plant | Cut-off, U
Electricity mix	Electricity, high voltage {FR}| electricity production, hydro run-of-river | Cut-off, U
Electricity mix	Electricity, high voltage {FR}| electricity production, nuclear, pressure water reactor | Cut-off, U
Electricity mix	Electricity, high voltage {FR}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U
Electricity mix	Electricity, high voltage {GR}| electricity production, oil | Cut-off, U
Electricity mix	Electricity, high voltage {IT}| electricity production, deep geothermal | Cut-off, U
Electricity mix	Electricity, high voltage {IT}| electricity production, hard coal | Cut-off, U
Electricity mix	Electricity, high voltage {IT}| electricity production, oil | Cut-off, U
Electricity mix	Electricity, high voltage {IT}| heat and power co-generation, biogas, gas engine | Cut-off, U
Electricity mix	Electricity, high voltage {IT}| heat and power co-generation, natural gas, combined cycle power plant | Cut-off, U
Electricity mix	Electricity, high voltage {IT}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | Cut-off, U
Electricity mix	Electricity, high voltage {IT}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U
Electricity mix	Electricity, high voltage {NL}| electricity production, hard coal | Cut-off, U
Electricity mix	Electricity, high voltage {OIT}| electricity production, hydro, reservoir, alpine region | Cut-off, U

Stage/Comment	ecoinvent dataset name
Electricity mix	Electricity, high voltage {PL}| heat and power co-generation, hard coal | Cut-off, U
Electricity mix	Electricity, high voltage {PL}| heat and power co-generation, lignite | Cut-off, U
Electricity mix	Electricity, high voltage {PL}| heat and power co-generation, wood chips, 6667kW, state-of-the-art 2014| Cut-off, U
Electricity mix	Electricity, high voltage {PT}| electricity production, deep geothermal | Cut-off, U
Electricity mix	Electricity, high voltage {RO}| electricity production, lignite | Cut-off, U
Electricity mix	Electricity, high voltage {SE}| electricity production, hydro run-of-river | Cut-off, U
Electricity mix	Electricity, high voltage {SE}| electricity production, nuclear, pressure water reactor | Cut-off, U
Electricity mix	Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U
Electricity mix	Electricity, high voltage {SE}| heat and power co-generation, wood chips, 6667kW, state-of-the-art 2014| Cut-off, U
Thermal mix	Heat, central or small-scale, natural gas {Europe without Switz.}| heat production, natural gas, at boiler condensing modulating <100kW | Cut-off, U
Thermal mix	Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, hard coal briquette, stove 5-15kW | Cut-off, U
Thermal mix	Heat, central or small-scale, other than natural gas {Europe without Switz.}| heat production, light fuel oil, at boiler 10kW, non-modulating |Cut-off, U
Thermal mix	Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, wood pellet, at furnace 9kW | Cut-off, U
Incineration	Waste polyethylene {Europe without Switzerland}| treatment of waste polyethylene, municipal incineration | Cut-off, U
Incineration	Waste polyethylene {Europe without Switzerland}| treatment of waste polyethylene, municipal incineration | Cut-off, U
Incineration	Waste expanded polystyrene {CH}| treatment of, municipal incineration | Cut-off, U
Incineration	Waste polyethylene {Europe without Switzerland}| treatment of waste polyethylene, municipal incineration | Cut-off, U
Incineration	Waste polyethylene terephtalate {Europe without Switzerland}| treatment of waste polyethylene terephtalate, municipal incineration | Cut-off, U
Incineration	Waste polypropylene {CH}| treatment of, municipal incineration with fly ash extraction | Cut-off, U
Incineration	Waste polystyrene {Europe without Switzerland}| treatment of waste polystyrene, municipal incineration | Cut-off, U
Incineration	Waste polyurethane {Europe without Switzerland}| treatment of waste polyurethane, municipal incineration | Cut-off, U

Stage/Comment	**ecoinvent dataset name**
Incineration	Waste polyvinylchloride {Europe without Switzerland}| treatment of waste polyvinylchloride, municipal incineration | Cut-off, U
Incineration	1 kg Waste plastic, mixture {Europe without Switzerland}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U (of project Ecoinvent 3 - allocation, cut-off by classification - unit)
Landfill	Waste plastic, mixture {Europe without Switzerland}| treatment of waste plastic, mixture, sanitary landfill | Cut-off, U
Mismanagement	Waste plastic, mixture {Europe without Switzerland}| treatment of waste plastic, mixture, sanitary landfill | Cut-off, U
Mismanagement	Plastic flake, consumer electronics, for recycling {IN}| plastic flake production, consumer electronics, for recycling, by grinding/shredding, informal sector | Cut-off, U
Mismanagement	Plastic granulate, unspecified, recycled {IN}| plastic granulate production, unspecified, recycled, informal sector | Cut-off, U
Mismanagement	Waste plastic, consumer electronics (waste treatment) {RoW}| treatment of waste plastic, consumer electronics, municipal incineration | APOS, U

Source: JRC modelling

Annex 3

3.1. Results of the sector-specific MFAs

Sector-specific results for the entire plastic value chain are provided in Table 16**.** Detailed assumptions and key results are explained in Section 2.4.1 and Section 3.1.

Table 16. Results of the sector-specific MFAs for the upstream level in the EU-27 for the year 2022. Possible rounding effects may be present in the data.

FROM	TO	P	C	T	E	A	TEX	F	H	O
Polymers production	Virgin polymers	21.55	12.84	4.59	3.19	2.47	1.45	0.18	0.21	10.71
Polymers production	Bioplastics	0.38	0.03	0.08	0.01	0.00	0.10	0.00	0.00	0.05
Import polymers	Demand	4.42	1.15	0.94	0.66	0.45	1.54	0.01	0.01	1.87
Demand	Export polymers	2.63	1.47	1.07	0.73	0.38	0.50	0.02	0.02	1.80
Manufacturing	Consumption	21.49	11.15	4.20	2.93	2.35	2.30	0.18	0.20	9.80
Manufacturing	Export Products	2.41	1.42	0.88	0.25	0.38	0.68	0.02	0.04	0.91
Import Products	Consumption	2.21	1.74	1.53	0.51	0.21	6.97	0.02	0.09	1.94
Manufacturing	Pre-consumer waste	2.20	1.39	0.34	0.21	0.19	0.28	0.00	0.00	0.84
Pre-consumer waste	Separated waste	2.20	1.39	0.34	0.21	0.19	0.28	0.00	0.00	0.84
Manufacturing	Losses manufacturing	0.02	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.19
Losses manufacturing	Microplastics	0.02	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.19
Losses manufacturing	Macroplastics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microplastics	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Microplastics	Soil	0.02	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.06
Microplastics	Recollected	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Macroplastics	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FROM	TO	P	C	T	E	A	TEX	F	H	O
Macroplastics	Soil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macroplastics	Recollected	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Consumption	Waste generated	19.71	2.84	2.45	2.74	1.52	6.18	0.07	0.24	6.79
Consumption	Losses consumption	1.00	0.06	0.46	0.00	0.02	0.02	0.01	0.01	0.01
Losses consumption	Microplastics	0.50	0.01	0.46	0.00	0.00	0.02	0.00	0.00	0.00
Losses consumption	Macroplastics	0.50	0.06	0.00	0.00	0.02	0.00	0.01	0.01	0.00
Microplastics	Water	0.00	0.00	0.08	0.00	0.00	0.01	0.00	0.00	0.00
Microplastics	Soil	0.50	0.01	0.32	0.00	0.00	0.00	0.00	0.00	0.00
Microplastics	Recollected	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Macroplastics	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Macroplastics	Soil	0.04	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Macroplastics	Recollected	0.46	0.05	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Waste collected	Prep. To Reuse and Reuse	0.00	0.00	0.14	0.04	0.00	0.75	0.00	0.00	0.00
Consumption	Stock	0.57	8.57	1.95	0.45	0.64	2.39	0.09	0.00	4.02
Waste generated	Export waste	0.46	0.34	0.11	0.00	0.03	0.64	0.00	0.00	0.21
Waste generated	Waste collected	17.70	2.19	1.54	1.91	1.42	5.46	0.07	0.23	6.11
Waste collected	Mixed waste	6.47	0.00	0.00	0.92	0.70	4.07	0.03	0.00	5.67
Waste collected	Separated waste	11.14	2.17	1.36	0.95	0.72	0.64	0.03	0.23	0.41
Waste collected	Composting waste	0.09	0.02	0.04	0.01	0.00	0.00	0.00	0.00	0.03
Waste generated	Losses waste	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Losses waste	Microplastics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Losses waste	Macroplastics	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01

FROM	TO	P	C	T	E	A	TEX	F	H	O
Microplastics	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microplastics	Soil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microplastics	Recollected	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macroplastics	Water	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macroplastics	Soil	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Macroplastics	Recollected	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mismanaged Waste	Recollected	0.25	0.00	0.17	0.18	0.00	0.00	0.00	0.00	0.09
Waste generated	Mismanaged Waste	1.15	0.30	0.79	0.82	0.07	0.07	0.01	0.01	0.41
Mismanaged Waste	Losses mismanaged	0.23	0.08	0.16	0.16	0.02	0.02	0.00	0.00	0.08
Losses mismanaged	Microplastics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Losses mismanaged	Macroplastics	0.23	0.08	0.16	0.16	0.02	0.02	0.00	0.00	0.08
Microplastics	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macroplastics	Water	0.04	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.01
Microplastics	Soil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macroplastics	Soil	0.13	0.04	0.09	0.09	0.01	0.01	0.00	0.00	0.05
Microplastics	Recollected	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macroplastics	Recollected	0.06	0.02	0.04	0.05	0.01	0.00	0.00	0.00	0.02
Mismanaged Waste	Unsanitary Landfill	0.35	0.12	0.24	0.25	0.03	0.03	0.00	0.00	0.13
Mismanaged Waste	Open Dump	0.32	0.11	0.22	0.23	0.03	0.03	0.00	0.00	0.12
Mixed waste	Mechanical Recycling	0.01	0.00	0.00	0.17	0.19	0.00	0.00	0.00	0.36
Mixed waste	Chemical Recycling	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00
Mixed waste	Incineration	4.09	0.00	0.00	0.46	0.29	2.35	0.02	0.00	3.54

FROM	TO	P	C	T	E	A	TEX	F	H	O
Mixed waste	Landfill	2.38	0.00	0.00	0.28	0.20	1.72	0.01	0.00	1.77
Separated waste	Mechanical Recycling	7.88	0.59	0.30	0.22	0.25	0.06	0.02	0.00	0.08
Separated waste	Chemical Recycling	0.09	0.03	0.02	0.01	0.02	0.06	0.00	0.00	0.00
Separated waste	Incineration	4.56	1.86	0.74	0.58	0.37	0.46	0.01	0.14	0.78
Separated waste	Landfill	0.80	1.08	0.64	0.35	0.26	0.34	0.00	0.09	0.39
Import waste	Mechanical Recycling	0.52	0.08	0.04	0.05	0.06	0.02	0.00	0.00	0.23
Mechanical Recycling	Incineration	1.76	0.23	0.13	0.20	0.19	0.03	0.01	0.00	0.23
Chemical Recycling	Incineration	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Mechanical Recycling	Landfill	0.20	0.03	0.02	0.02	0.02	0.00	0.00	0.00	0.03
Chemical Recycling	Landfill	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Mechanical Recycling	Recyclates	6.44	0.43	0.19	0.26	0.36	0.05	0.01	0.00	0.40
Chemical Recycling	Recyclates	0.08	0.02	0.02	0.02	0.03	0.05	0.00	0.00	0.00
Recyclates	Packaging sector	1.21	0.01	0.00	0.00	0.09	0.02	0.00	0.00	0.12
Recyclates	Building sector	1.21	0.42	0.01	0.06	0.07	0.04	0.01	0.00	0.16
Recyclates	Transport sector	0.23	0.00	0.09	0.11	0.00	0.00	0.00	0.00	0.01
Recyclates	EEE sector	0.08	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01
Recyclates	Agriculture sector	0.00	0.00	0.00	0.00	0.16	0.01	0.00	0.00	0.05
Recyclates	Textiles sector	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Recyclates	Other sector	3.78	0.03	0.10	0.08	0.07	0.00	0.00	0.00	0.05
Recyclates	Export recyclates	0.84	0.06	0.03	0.04	0.05	0.01	0.00	0.00	0.05
Incineration	Losses Incineration	0.21	0.04	0.02	0.02	0.02	0.06	0.00	0.00	0.09
Losses Incineration	Microplastics	0.21	0.04	0.02	0.02	0.02	0.06	0.00	0.00	0.09

FROM	TO	P	C	T	E	A	TEX	F	H	O
Microplastics	Water	0.10	0.02	0.01	0.01	0.01	0.03	0.00	0.00	0.05
Microplastics	Soil	0.10	0.02	0.01	0.01	0.01	0.03	0.00	0.00	0.05
Incineration	Landfill	0.39	0.08	0.03	0.05	0.03	0.11	0.00	0.01	0.17
Landfill	Losses Landfill	0.06	0.02	0.01	0.01	0.01	0.03	0.00	0.00	0.04
Losses Landfill	Microplastics	0.06	0.02	0.01	0.01	0.01	0.03	0.00	0.00	0.04
Microplastics	Water	0.03	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.02
Microplastics	Soil	0.03	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.02
Recycled polymers	Manufacturing	5.68	0.39	0.18	0.25	0.34	0.08	0.01	0.00	0.35

Source: JRC Modelling. Note: P = Packaging; C = Construction, T = Transport, E = Electronic, A = Agriculture, TEX = Textiles, H = Healthcare, F = Fishing, O = Other

3.2. Results of the polymer-specific MFAs

In all the following Sankey diagrams developed via an ad-hoc tool (Section 2.1), the flows of recycled polymers circulating to the manufacturing stage were included for visual representation purposes. However, it should be considered that each flow of recycled plastics is numerically connected in the model to its specific sector of destination (based on the specific 'recyclates fate').

Figure 13. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the Packaging sector. All data are expressed in Mt [Megatonnes] and refer to the year 2022.

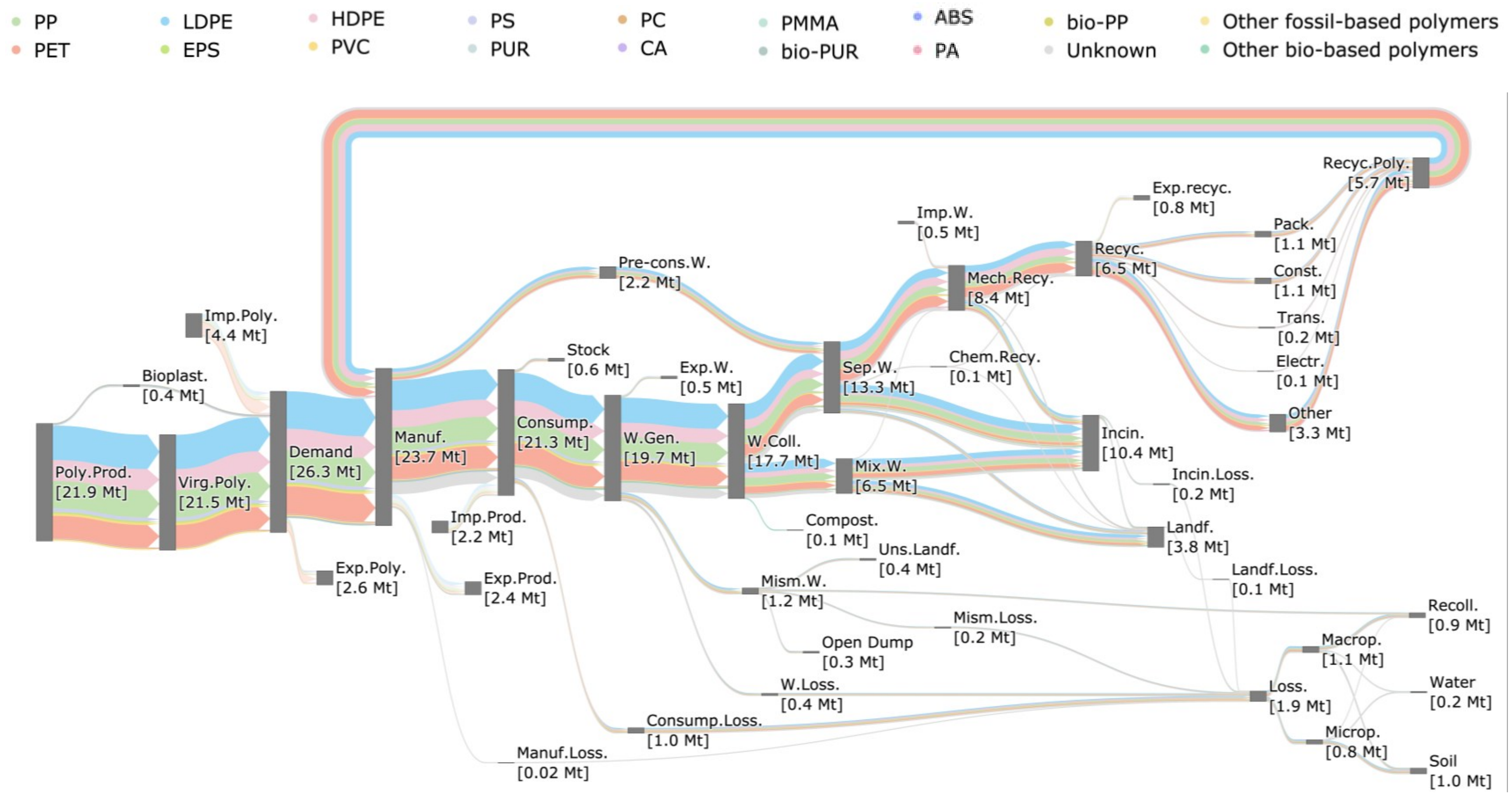
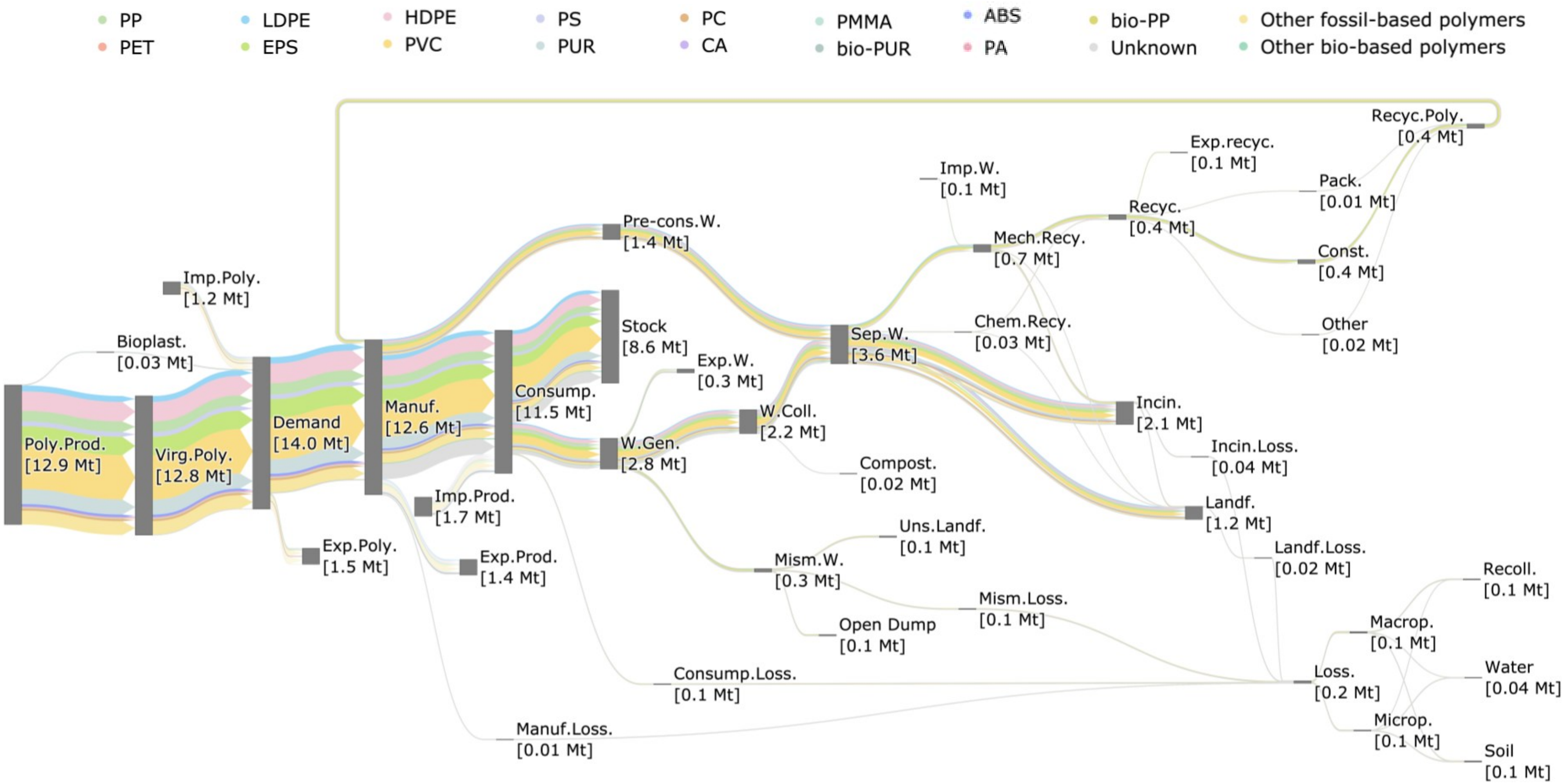
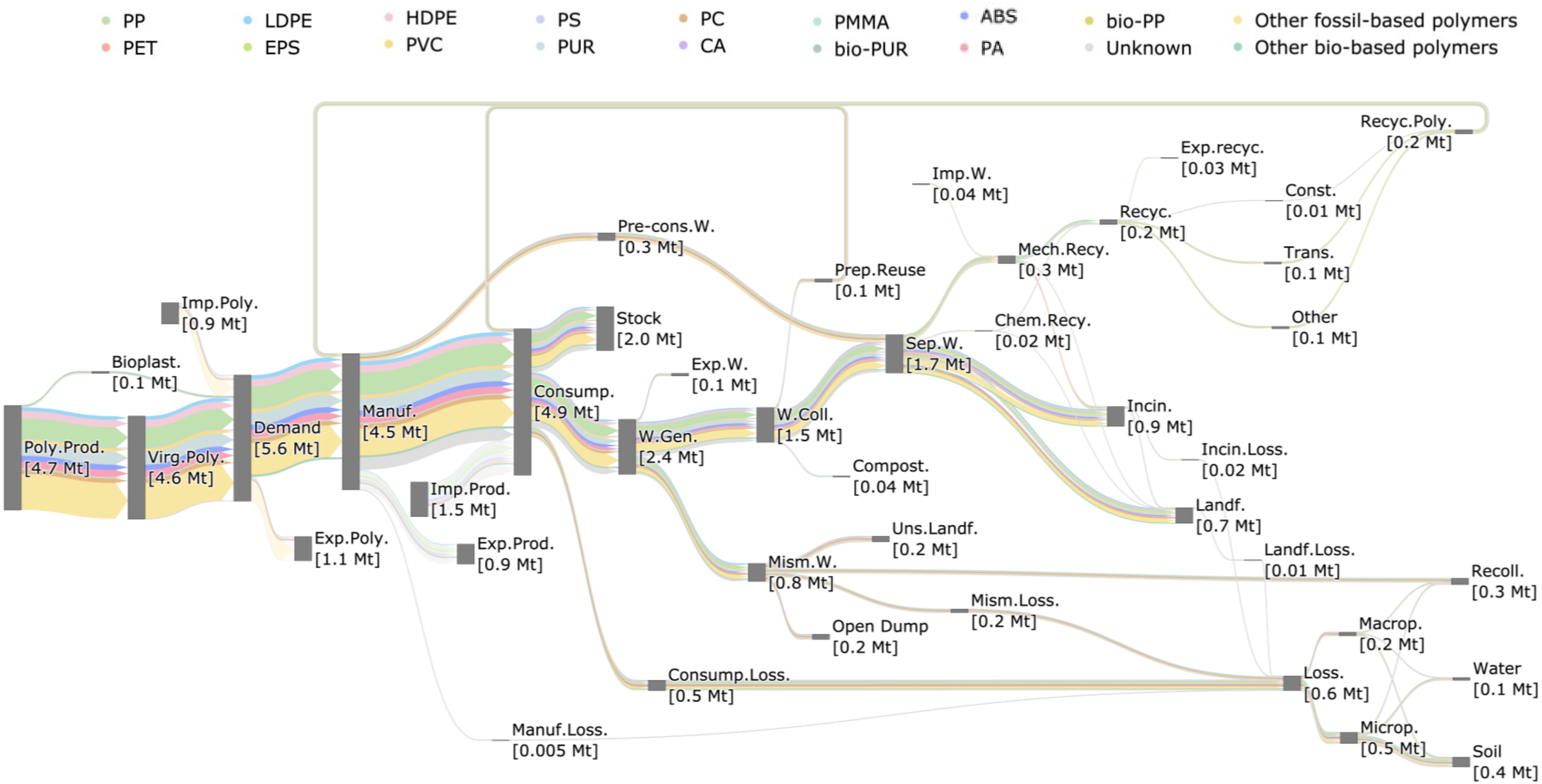


Figure 14. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the Construction sector. All data are expressed in Mt [Megatonnes] and refer to the year 2022.



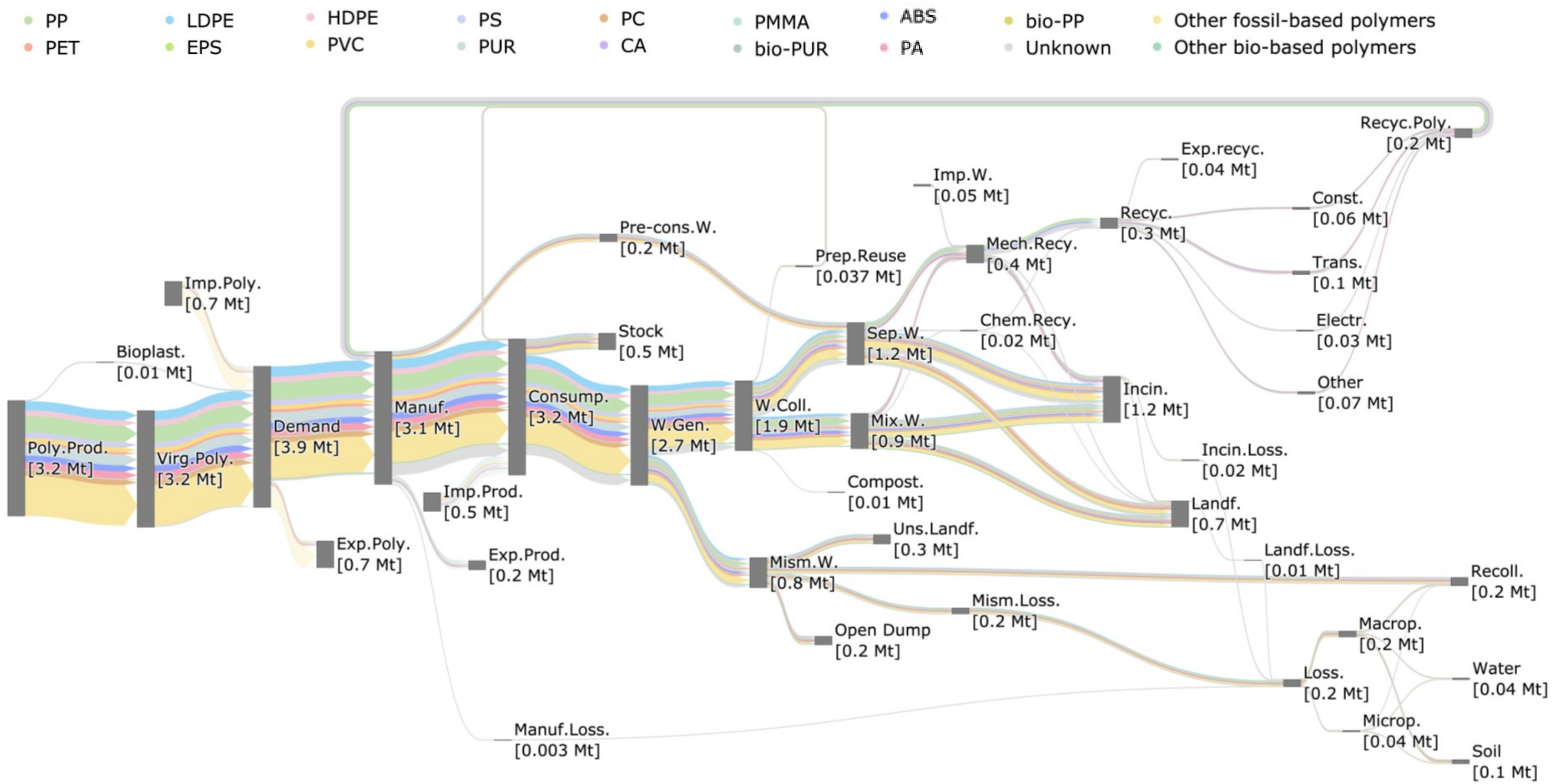
Source: JRC elaboration.

Figure 15. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the Transport sector. All data are expressed in Mt [Megatonnes] and refer to the year 2022.



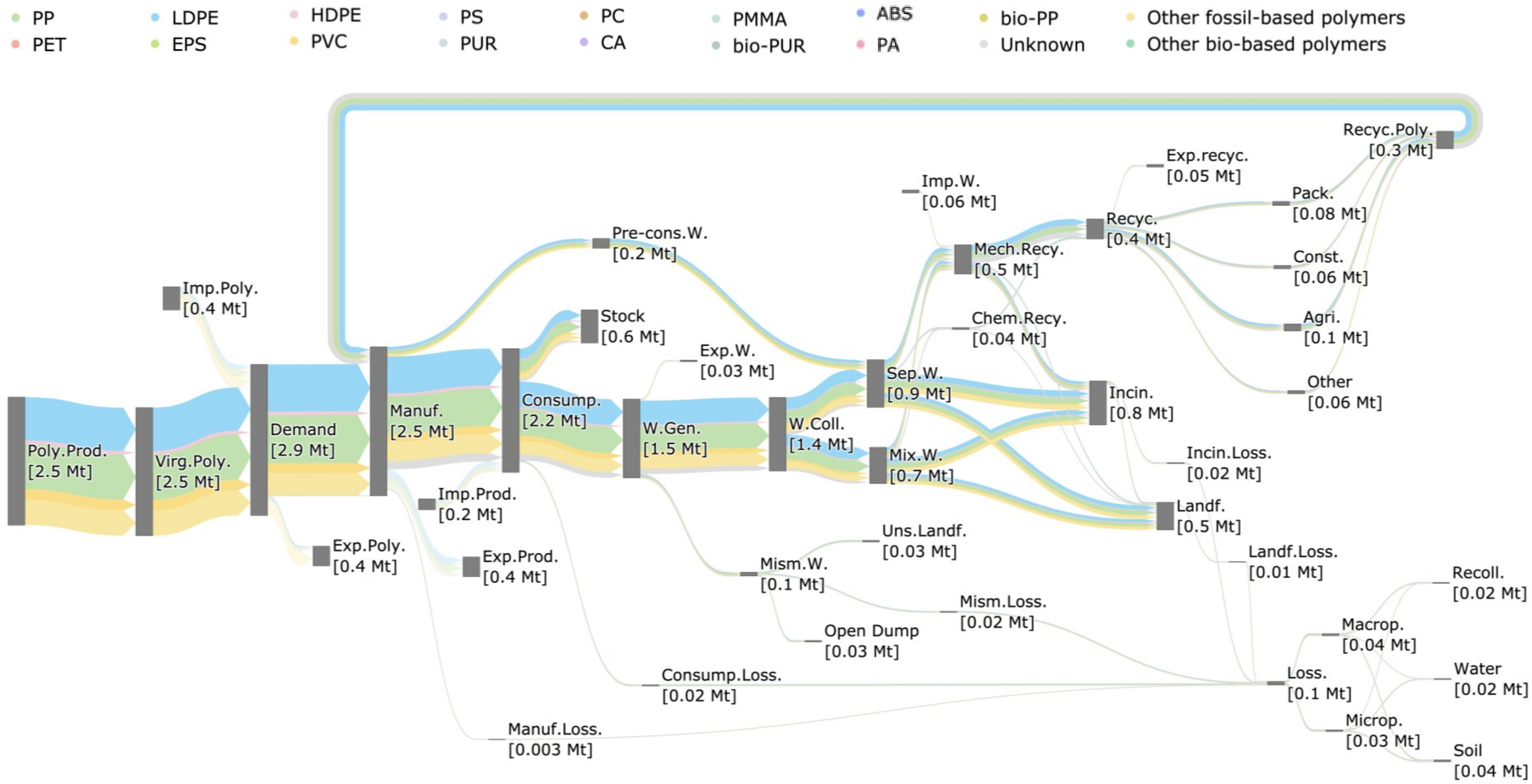
Source: JRC elaboration.

Figure 16. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the Electronic sector. All data are expressed in Mt [Megatonnes] and refer to the year 2022.



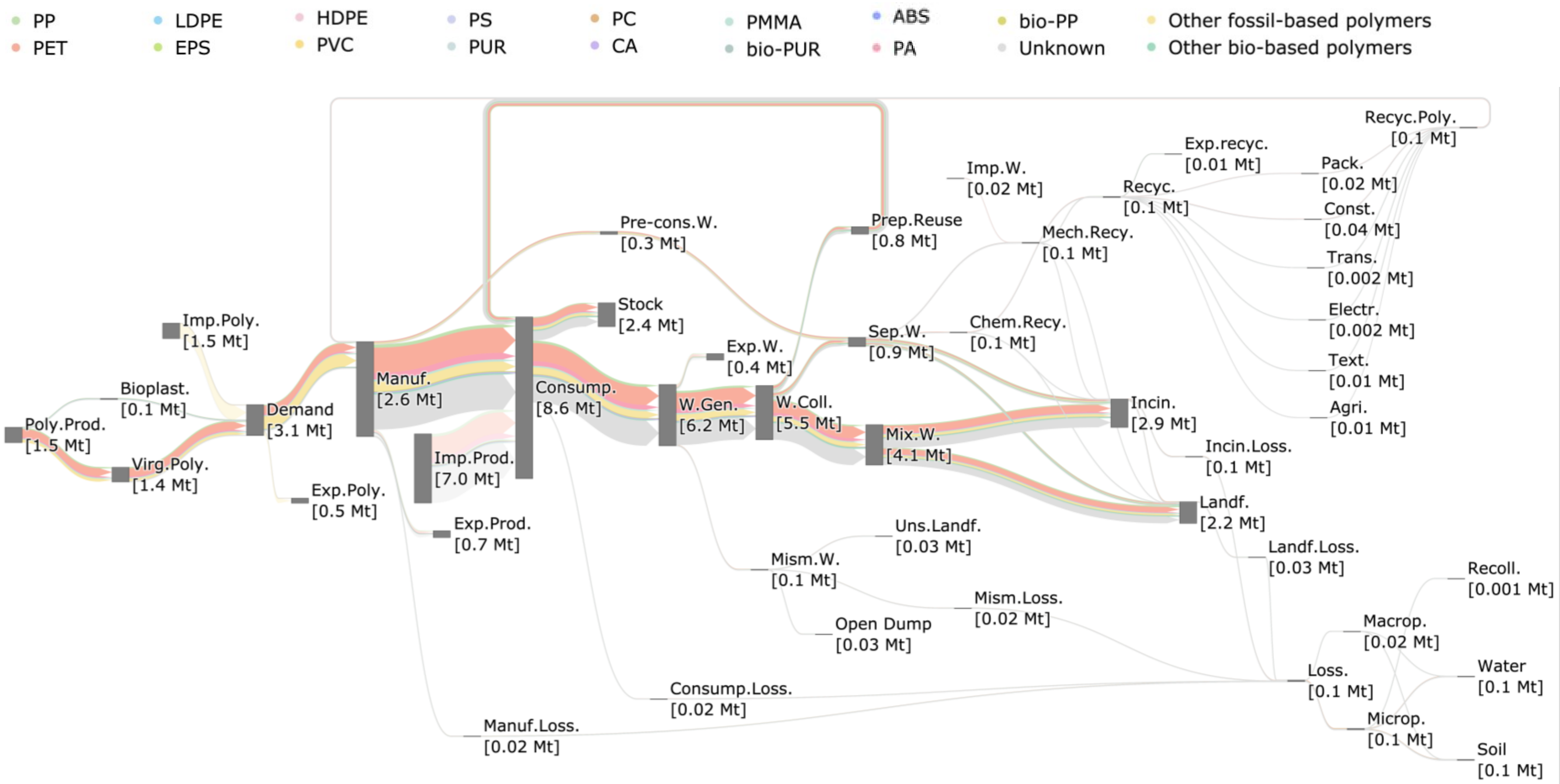
Source: JRC elaboration.

Figure 17. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the Agriculture sector. All data are expressed in Mt [Megatonnes] and refer to the year 2022.



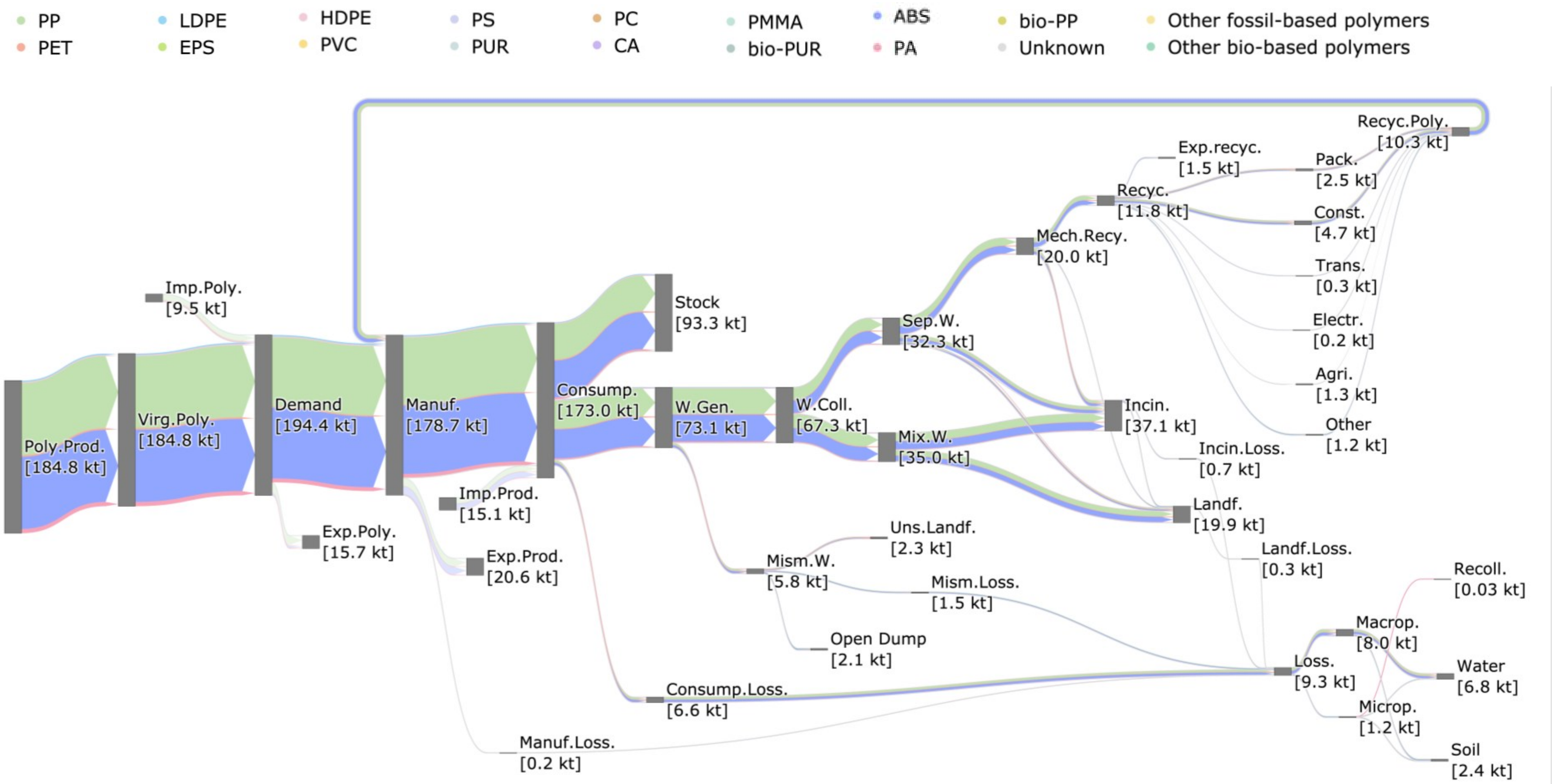
Source: JRC elaboration.

Figure 18. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the Textiles sector. All data are expressed in Mt [Megatonnes] and refer to the year 2022.



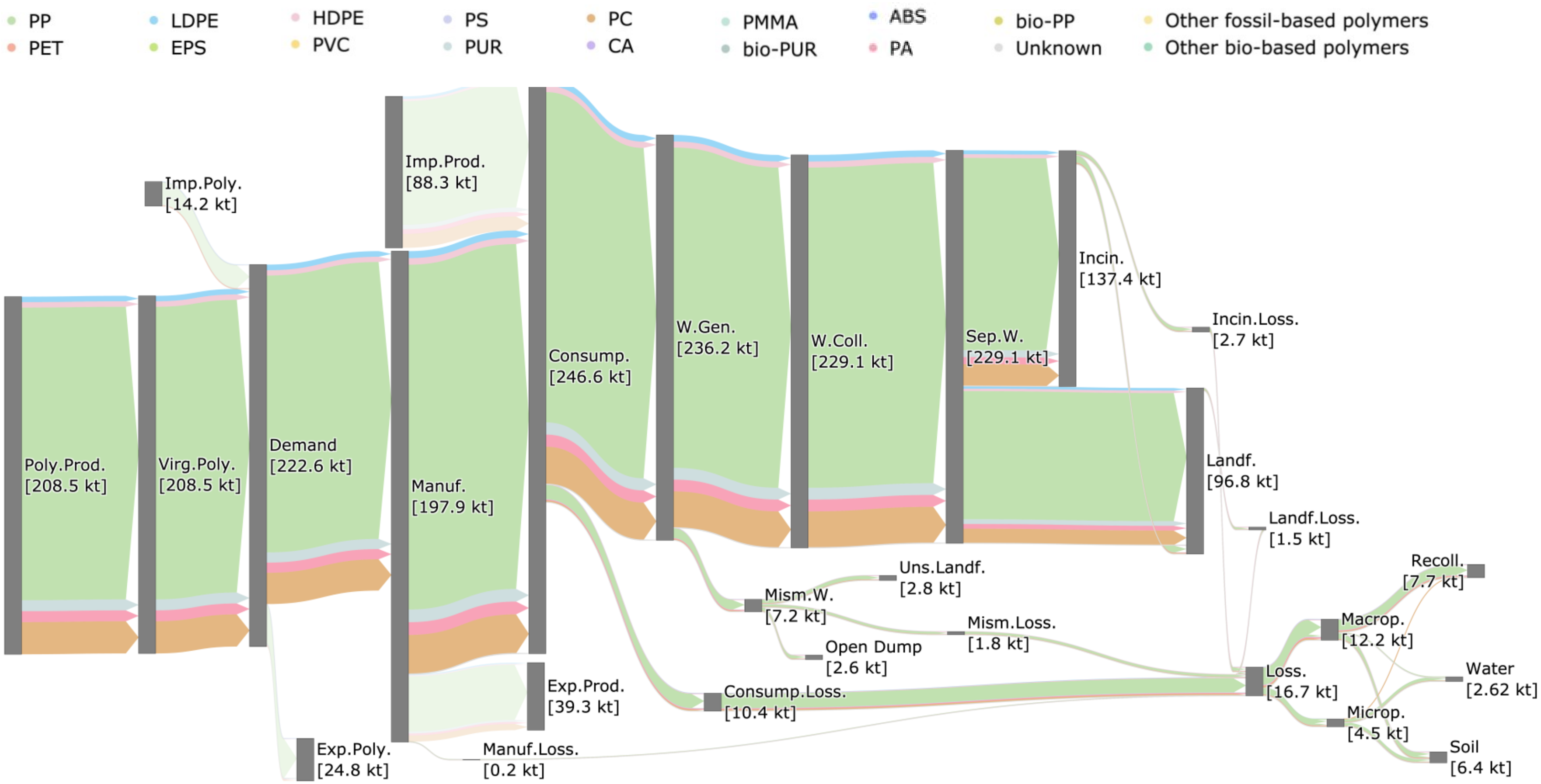
Source: JRC elaboration.

Figure 19. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the Fishing sector. All data are expressed in kt [kilotonnes] and refer to the year 2022.



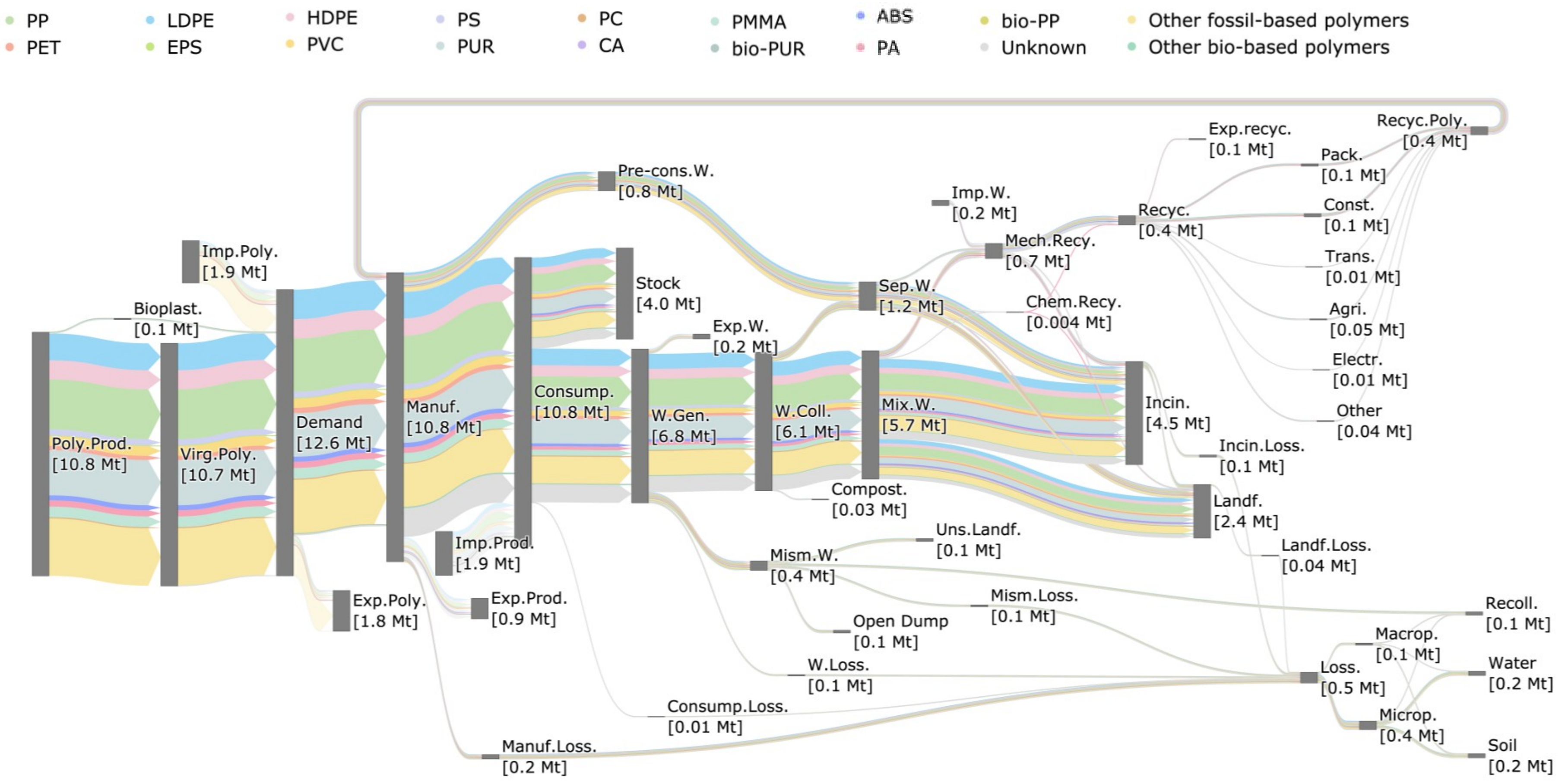
Source: JRC elaboration.

Figure 20. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the Healthcare sector. All data are expressed in kt [kilotonnes] and refer to the year 2022.



Source: JRC elaboration.

Figure 21. Sankey diagram of the material flow analysis of EU-27 plastic flows at level of polymers for the 'Other' sector. All data are expressed in Mt [Megatonnes] and refer to the year 2022.



Source: JRC elaboration.

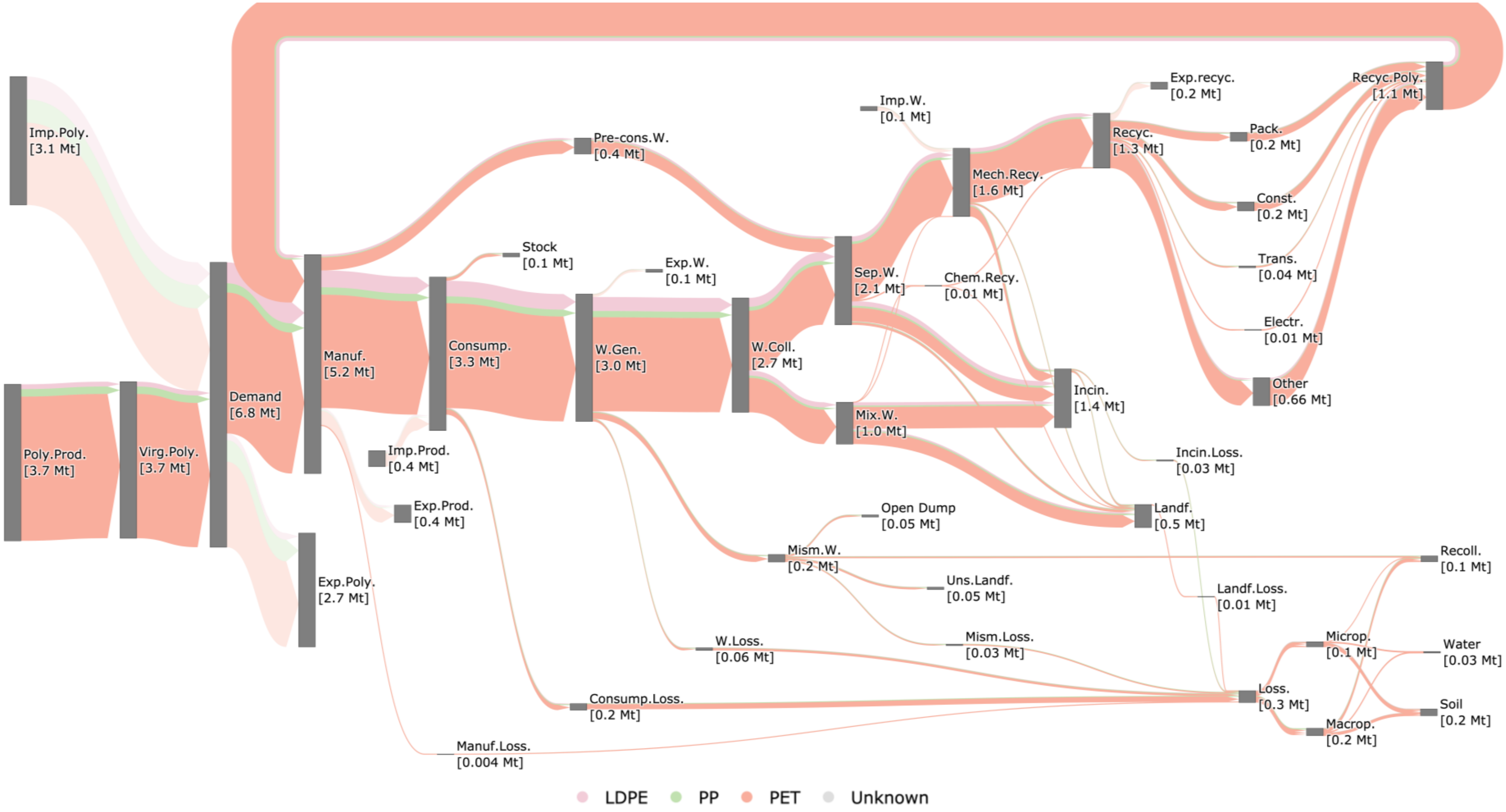
3.3. Results of the product-specific MFAs

In the present report, this novel product-specific approach offers a flexible and replicable methodology, that could potentially also be applied to other product-specific MFAs even beyond plastics. However, it is notably outlined that this approach is not implemented with product-specific insights, resulting in key findings that rely on estimates derived from polymer-specific MFA, which may introduce a limitation.

The developed methodology was applied to the flat screen and PET bottle products as follow:

- **Flat screen**: information related to the weight (10.5 kg, considering 5.7 kg for monitors and 15.1 kg for TV display) and polymers' share (3% HDPE, 1% PP, 10% PVC, 4% PUR, 38% ABS, 21% PC, 23% Other fossil-based polymers) of this product were retrieved by Salhofer et al., (2011). Plastics accounted for approximately 37% of the total materials composing the modelled flat screen (EFRA, 2014), with the other 63% being mostly covered by iron and steel. Flat screens represent 8.0% of total products in the electronic sectors (Euromines, 2020).
- **PET bottle**: based on a study shared during the stakeholder consultation the weight of the modelled PET bottled (26.2 g) was retrieved from Conversio report (Conversio Market & Strategy GmbH, 2022). On top of the PET bottle body (92% of the total mass), the modelled PET bottle included (i) a PP cap (contributing to 5% of the total mass; Sinkko et al., 2024), and a (ii) LDPE label (3%, based on own empirical weight analysis). Furthermore, PET bottles represent a considerable proportion of the Packaging sector, with an estimated share of 17% of total products (Eunomia, 2022).

Figure 22. Sankey diagram of the material flow analysis of EU-27 plastic flows related to PET bottles. All data are expressed in Mt [Megatonnes] and refer to the year 2022.



Source: JRC elaboration.

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