Modelling the EU plastic value chain and assessing its environmental impacts: approaches, data sources and hotspots towards a circular plastic value chain

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Abstract

Despite the increasing attention to the European Union (EU) plastic flows, there is a lack of studies focusing on comprehensive assessments of the plastics value chains, across various sectors and polymers, both at the level of mass flows and at the level of environmental impacts. This deficiency is especially evident in the lack of consideration given to certain specific plastic sectors or to certain specific plastic flows such as plastic losses, mismanaged waste plastics, or the fate of recycled plastics. The EU has striven to tackle the plastic challenge through several key policy initiatives such as the EU Plastic Strategy [1] (flagging how plastics are currently produced, used, and discarded in way that leads to severe environmental impacts) and the Circular Economy Action Plan [2] (aiming at further developing a circular economy also for the plastic sector). The prevention and reduction of plastics impacts, especially due to single-use-plastics, has also been at the forefront of the EU attention, as highlighted in the Single-Use Plastics (SUP) [3]. A specific focus on plastic has also been outlined in the EU Green Deal [4], which not only aims at reducing intentionally added microplastics and unintentional releases of plastics, but also at ensuring that all packaging in the European market is reusable or recyclable in an economically viable manner by 2030. Understanding the impact of plastic pollution, particularly marine plastic debris, has also been recognized as critical for achieving UN Sustainable Development Goal (SDG) 14, aimed at conserving and sustainably utilizing oceans, seas, and marine resources [5]. Achieving the ambitious goals set forth by these actions needs a profound understanding of the flow of plastic materials within the EU.

This study developed a comprehensive top-down Material Flow Analysis (MFA) covering the entire value chain across nine economic sectors and focusing on ten specific polymers within the EU27 in 2019. MFA has in fact been employed in the recent years as a key tool for assessing products flows and to unveil hotspots of value chains that could hinder circularity and sustainability [6], [7], [8]. Sector-specific MFAs were computed using sets of Transfer Coefficients (TCs) matrices at the level of sectors and polymers. TCs are defined for each input and output flows of a process along the value chain and serve the purpose of detailing the total amount of a substance that is transferred from a process to another one. The MFA was also linked to a Life Cycle Assessment (LCA) analysis, aimed at unveiling the environmental impacts of the whole value chain and at providing methodological guidance on linking LCA with MFA results.

During the initial phase of the project, a thorough literature review was conducted to gather pertinent data, with a focus on identifying key literature sources. Subsequently, data adjustments were made to adjust data to a common reference point (EU27 2019) and to adapt the information to suit the system boundaries of the abovementioned sectors-specific and polymers-specific value chains under exam.

Employing a tailor-made top-down approach, the total EU plastic demand was differentiated by sectors and polymers and the fate of each plastics flow was followed from manufacturing to the end-of-life. The findings from the sector-specific MFAs are displayed in Figure 1.

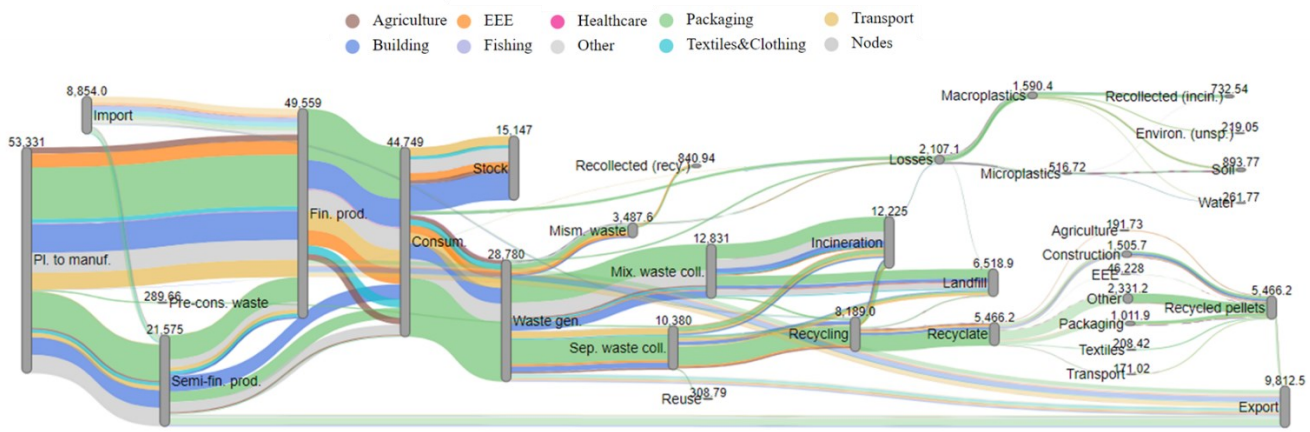

Figure 1. Overview of the EU27 2019 MFA for all the examined sectors. All data are expressed in ktonne.

The results emphasized the crucial role played by the packaging sector in the whole EU plastic value chain, as this sector amounted to 33% of the total plastic consumption, followed by the construction sector at 23%. Waste generated from consumption constituted 64% of total consumed plastics, with 34% ending up in “stock” and 2% lost during use. In the present study, the “stock” accumulation across all included sectors was determined by calculating as the amount of plastics balancing the total consumed amount and the total waste generated amount within each sector. Notably, the study revealed a gap of approximately 15 million tonnes between total consumed plastics and total waste generated in 2019 (gap which has been also recognized by other literature and report in the plastic field; e.g. [9]). A recent report by Material Economics and Agora Industry [10] indicates that this gap may be attributable to an underestimation, potentially as high as 45%, of the total mixed waste generated and collected.
Despite the significant amount of post-consumer waste generated in 2019 (28.8 million tonnes), only 38% was separately collected, and a notable fraction (13%) was mismanaged, particularly impacting the transport (44% of the total waste generated) and EEE (22% of the total waste generated) sectors. Plastic “mismanagement” was intended in this study as inadequately disposed waste - e.g., disposed in open dumps, unspecified landfills, unaccounted, etc. and/or treated/managed for example by unauthorized third parties - in ways that could create routes for potential losses and releases into the environment. Part of this waste could also be potentially recollected by waste pickers or informal collection systems and sent to recycling. Plastic mismanagement was recognized by the present study as a key hotspot in the EU plastic value chain, leading to an overall loss of valuable plastic fractions that could otherwise be directed to proper end-of-life management.

When looking at recycling, 70% of the plastic waste entering recycling facilities (being equal to a total of 8 million tonnes) originated from the packaging sector. Overall, 5.47 million tonnes of recyclates (i.e., secondary recycled plastics) were produced in the EU27 in 2019, with 4.46 million tonnes consumed domestically (considering 18% exported).
Despite uncertainty and data limitations in modelling the fate/destination of recyclates, the construction sector emerged as the primary destination for secondary plastics, followed by the packaging sector. The EU27 end-of-life recycling rate averaged to 19% (16.6% when trade effects are considered).

A significant amount (2.11 million tonnes) of microplastics and macroplastics losses in the entire value chain occurred during the use phase (39% due to e.g. emissions caused by tyre abrasion or washing of synthetic textiles). Losses of waste plastics could also occur (amounting to 37% of the total losses and including 20% due to plastic waste littered and 17% due to mismanaged waste not recollected). Lastly, 2.5% of plastics is lost during pre-consumption phases and 21.5% from incineration and landfill (11.6% and 9.90%, respectively).

Despite these findings, the estimated 4.46 million tonnes of recyclates used in the EU27 in 2019 would not meet the EU [1] target of 8.8 million tonnes to be recycled and consumed within the Union by 2025[1]. A series of scenarios were therefore developed to assess how the 2019 sector-specific MFAs could change for the year 2025, with the aim of aligning such changes with expected trends in the plastic value chain also as a consequence of EU plastic policies targets. These scenarios were crafted based on anticipated developments in the plastic value chain, considering key EU policies [11], [12], [4], international initiatives such as China's ban on waste imports [13], and insights from significant literature sources [14]. These potential improvements were reflected in alterations to the TCs, thereby representing hypothetical future changes in the value chain. The scenarios encompassed various aspects including for instance "reduced waste export", "improved waste collection", "improved recycling performance", etc. or scenarios combining multiple interventions along with variations in plastic production (e.g., +10%/-10% compared to the 2019 base results).
When combined with variations in plastic production, the EU target could be surpassed by 2025: notably, assuming a +10% production increase, a total recyclates consumption of 11.13 million tonnes could be realized by 2025. Considering trends in plastic packaging production, which suggest a yearly increase of around 4-5%, coupled with the impacts of events like the COVID-19 outbreak and the Ukraine war, a reduction in plastic production could be foreseeable. Even in the case of scenarios considering a 10% reduction in plastic production instead of a 10% increase, a total recyclates consumption of 9.11 million tonnes is achievable, meeting the EU target [1].

This study underscores the necessity for significant efforts to enhance the granularity and detail of plastic flow overviews in the EU to meet EU ambitions and industry targets like the EU target [1]. While packaging undoubtedly holds a central role in the EU plastic value chain, there is a pressing need to refine and bolster the analysis of less-explored sectors in the coming years. This is especially relevant for sectors like synthetic textiles, fishing, and healthcare, which remain largely unexplored in current literature. Despite challenges, such as data aggregation and sector-specific information gaps, concerted efforts are needed to enhance plastic flow monitoring frameworks and realistic assessments of future plastic flows to realize the untapped potential for additional and improved recycling in the plastic value chain. In conclusion, addressing plastic flows in the EU requires multisectorial approaches, with particular attention to improving plastic waste collection and considering alternative recycling processes. Despite uncertainties, achieving EU targets could be feasible with dedicated efforts and up-to-date knowledge not only of the plastic value chain's key flows but also less-explored ones.

In a second phase of the work, a LCA of the EU plastic value chain was performed. In fact, to date, few studies have tried to combine MFA to LCA in view of providing a complete overview of flows and impacts of the plastic value chain in Europe. The LCA aims at assessing the total emissions of the EU plastic value chain from raw materials manufacturing to end-of-life waste management and recycling, covering

[1] *To enable a fair comparison with the results of the present study, the EU target of 10Mt for EU27+UK was corrected to EU27 considering: (i) the ratio between the plastic demand in UK and the plastic demand in EU27+UK (equal to 7%), and that (ii) the amount of preconsumer PVC recyclates (approximately equal to 0.5Mt) from and used in construction sector is to be included in the 10Mt target.*

the 16 impact categories of the Product Environmental Footprint (PEF) [15]. The goal of the analysis is to assess the environmental impacts of all plastic flows modelled through the MFA, covering the impacts associated with each polymer in each sector and also covering the potential environmental pressures due to less-explored sectors (e.g., plastics in the healthcare and fishing sectors) and less-explored flows (e.g., plastics losses and plastic waste mismanagement). An overview of the methodological approach for assessing the life cycle impacts of the plastic value chain in accordance to the existing MFA plastic model will be provided, coupled with evidences related to the key drivers of the EU plastic value chain impacts and the key barriers to overcome for lowering its environmental pressures.

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