LABPLAS

Horizon 2020
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LABPLAS

Land-Based Solutions for Plastics in the Sea

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D8.1 Interim report describing the supply chain of two case studies

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3	Bundesanstalt fuer Gewaesserkunde	BfG	GERMANY	RTO
4	LABORATORIO IBERICO INTERNACIONAL DE NANOTECNOLOGIA	INL	PORTUGAL	RTO
5	KATHOLIEKE UNIVERSITEIT LEUVEN	KUL	BELGIUM	HES
6	HELMHOLTZ ZENTRUM FUR OZEANFORSCHUNG KIEL	GEOMAR	GERMANY	RTO
7	NATIONAL OCEANOGRAPHY CENTRE	NOC	UNITED KINGDOM	RTO
8	SORBONNE UNIVERSITE	SU	FRANCE	HES
9	OPEN UNIVERSITEIT NEDERLAND	OUNL	NETHERLANDS	HES
10	LEIBNIZ INSTITUTE FOR BALTIC SEA RESEARCH	IOW	GERMANY	RTO
11	ASSOCIACAO PARA O DESENVOLVIMENTO DO ATLANTIC INTERNATIONAL RESEARCH CENTRE	AC	PORTUGAL	RTO
12	UNIVERSIDADE FEDERAL DO SAO PAULO	UNIFESP	BRAZIL	HES
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Executive summary:	This document corresponds to Deliverable 8.1. *Interim Report describing the supply chain of two case studies,* developed in the framework of Task 8.1 of the LABPLAS project. This report provides a first insight into the effectiveness of potential emission reduction measures for two case studies: 1. Tyre wear (Lead RU and OU) 2. Single-use plastics (Lead UVI-Erenea) The approach taken for each case study includes the identification of relevant key stakeholders, mapping of the typical supply chain from cradle to grave, an estimate of the typical SMNP emissions to the environment at the different stages of the supply chain and the formulation of potential intervention options. This interim report will feed D8.2. *Report describing the effectiveness of emission reduction measures of SMNPs for the two case studies*.

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Disclaimer

The views and opinions expressed in this document reflect only the authors' views, and not necessarily those of the European Commission.

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ABBREVIATIONS AND ACRONYMS

Abbreviation / Acronym	Description
ASTM	American Society for Testing and Materials
BAT	Best Available Technology
CLSC	Closed Loop Supply Chain
CSR Europe	European Business Network for Corporate Sustainability and Responsibility
EC	European Commission
EEA	European Environmental Agency
EF	Emission Factor
EoL	End-of-Life
EoP	End-of-Pipe
EPA	United States Environmental Protection Agency
EPR	Extended Producer Responsibility
EQS	Environmental Quality Standards
ETRMA	European Tyre Manufacturers Association
EU	European Union
EUPC	European Plastics Converters
ISO	International Standards Organization
LCA	Life Cycle Assessment
LDPE	Low-Density Poly Ethylene
MSA	Material System Analysis
NGO	Non-Governmental Organization
PBAT	Poly Butylene Adipate Terephthalate
PE	Poly Ethylene
R&D	Research & Development
SCOR	Supply Chain Operations Reference
SMNP	Small, micro- and nano- plastics
SUP	Single Use Plastic
SUPD	Single Use Plastics Directive
SUV	Sports Utility Vehicle
TRWP	Tyre and Road Wear Particles
TWP	Tyre Wear Particles
UNDP	United Nations Development Programme
WWTP	Waste Water Treatment Plant

1 INTRODUCTION

Plastic is pouring from land into our oceans at a rate of nearly 10 million tonnes a year (UNEP, 2021). Once in the sea, plastics fragment into particles moving with the currents and ocean gyres before washing up on the coastline. The smaller the size the higher the risk posed by these particles to organisms and human health. Because small, micro- and nano-plastics (SMNP) cannot be removed from oceans, proactive action regarding research on plastic alternatives and strategies to prevent plastic from entering the environment should be taken promptly. The LABPLAS project is a 48-month project whose vision is to develop new techniques and models for the detection and quantification of SMNPs Specifically, the LABPLAS project will determine reliable identification methods for a more accurate assessment of the abundance, distribution, and toxicity determination of SMNPs and associated chemicals in the environment. It will also develop practical computational tools that should facilitate the mapping of plastic-impacted hotspots and promote scientifically sound plastic governance.

This report provides a first insight into the effectiveness of potential emission reduction measures for two case studies:

1. Tyre wear (Lead RU and OU)
2. Single-use plastics (Lead UVI-Erenea)

The approach taken for each case study includes:

a. Identification of relevant key stakeholders
b. Map of the typical supply chain from cradle to grave
c. Estimate of the typical SMNP emissions to the environment at the different stages of the supply chain
d. Formulation of potential intervention options

This interim report will feed D8.2. *Report describing the effectiveness of emission reduction measures of SMNPs for the two case studies*.

2 Case Study 1: Tyre wear emissions

Tyre wear is responsible for an important part of the microplastics detected in the environment (Boucher & Friot, 2017; Kole et al., 2017), e.g., in the form of tyre and road wear particles (TWRP). Tyre wear is the result of mechanical forces caused by the contact between tyres and the road surface while driving (Panko et al., 2013; Sieber et al., 2020; Wagner et al., 2018). Even though tyre wear is a major source of microplastics, microplastics release also occurs during other stages of the tyre's lifecycle, e.g., when granulated tyres are being used as infill for artificial turfs (Kole et al., 2017). In the current report, we use the term "tyre microplastics" to refer to all microplastics that originate from tyres.

The important contribution of tyres to microplastics found in the environment triggers the question of how emissions from tyres can be reduced effectively and efficiently. Answering this question is not straightforward as many interventions are possible. These vary from source-oriented measures, such as changing the composition of tyres, to end-of-pipe solutions, such as capturing and treating road runoff (Furuseth & Rødland, 2020; OECD, 2021). Whether an intervention is feasible depends on factors such as its effectiveness in reducing tyre microplastics emissions, its costs and (upstream) implications for important stakeholders, such as the tyre industry. Therefore, the planning of such interventions does not only require detailed insight into the environmental sources, pathways and effects of tyre microplastics (Mitrano & Wohlleben, 2020) but also requires an integrative multi-stakeholder approach (Mian et al., 2022). Stakeholder involvement is critical as it provides a way to better understand the complexity of a problem and the diversity of perspectives around it, and it builds trust for further collaboration necessary for the exploration of, in this case, robust and realistic mitigation measures (Chua, 2016; Pohl & Hirsch Hadorn, 2007). Additionally, it facilitates data gathering and the validation of results (Diedrich et al., 2011; Oreskes, 2004).

The first step towards a multi-stakeholder mitigation strategy is to create a systematic overview of the processes associated with the tyre's lifecycle, how these relate to microplastic emissions, but also of the stakeholders involved, their interests and interrelations. The aim of the current case study is therefore to create the foundation for the development of an emission mitigation strategy for tyre wear by mapping the tyre supply chain, its emissions of tyre microplastics, the stakeholders involved, their potential roles and interdependencies, all in close collaboration with stakeholders. The models' system boundaries were set to the Netherlands and the year 2021. This decision was based on data availability and good contact with key stakeholders in this region. Three types of tyres were included in this study: passenger car tyres (including van and caravan tyres), bus tyres and truck tyres.

2.1 Map of the supply chain

2.1.1 Methods

As a starting point, the Closed Loop Supply Chain (CLSC) of a tyre was mapped. The CLSC refers to all forward logistics in the chain, such as extraction and production, while at the same time including the collection and processing of returned (End-of-Life) products and/or parts (Bloemhof-Ruwaard et al., 2002). To describe and map the tyre's supply chain map, the SCOR model was used. SCOR is a process reference model for supply chain management endorsed by the Supply Chain Council (SSC, 2012). SCOR aims to facilitate the mapping, assessment and evaluation of processes and activities in the supply chain to improve and streamline processes (SSC, 2012).

Firstly, the different lifecycle stages present in the supply chain were distinguished. Then the processes in each lifecycle stage were identified and mapped by means of a visual representation. Only processes related to (tyre) material streams were included, thus, excluding those related to information streams, such as receiving orders and customer contact. Information to create the supply chain was initially obtained from peer-reviewed and grey literature. Literature was found via a web-based search engine with keywords including: ‘tyres/tyres’, ‘supply chain’, ‘manufacturing’, ‘collection’, and ‘End-of-Life’. A tyre manufacturing plant and R&D department was visited to obtain insight into the tyre manufacturing process. Open interviews were conducted with specific stakeholders to acquire additional knowledge or to validate information found in the literature. The supply chain map was discussed for validation with stakeholders during a workshop.

2.1.2 Results

The tyre’s lifecycle starts with the mining and production of raw materials from which a tyre is constructed. The subsequent manufacturing of a tyre consists of different stages, i.e., mixing, component manufacturing, tyre building, tyre curing and final inspection (Continental, n.d.; Shanbag & Manjare, 2020). After production, tyres are distributed via car manufacturers as part of a new vehicle or via the numerous tyre distributors on the replacement market. After a tyre is disposed of, it is collected and distributed based on its quality. Tyres with more than the legal minimum tread depth can be sold on the internationally used tyre market. Tyres of which the carcass is still of sufficient quality can also be retreaded, which is more common for bus and truck tyres. The remaining tyres are End-of-Life Tyres, of which the main portion is mechanically recycled (RecyBEM, 2022). The rubber granulate that is produced can be used in a number of applications.

Figure 1 shows the supply chain map, in which both the processes per lifecycle stage and the material streams between them are presented. The tyre’s lifecycle stages are shown in relation to the primary stakeholder group, i.e., suppliers of raw ingredients, tyre manufacturers, distributors, consumers and processors of used tyres, which includes used tyre collectors. As with most contemporary supply chains, the tyre’s supply chain is a global system. The overall forward supply chain system is, therefore, relatively universal. However, the return tyre collection system and diversity of End-of-Life trajectories are specific to the Netherlands. After analyzing all processes in terms of individual inputs and outputs relevant to microplastic release, it was determined that tyre usage by consumers and rubber granulate, when used as infill for artificial turfs, are relevant for tyre microplastic emissions to the environment. Microplastic release from other processes was considered to be negligible, relatively limited or without release to the environment.

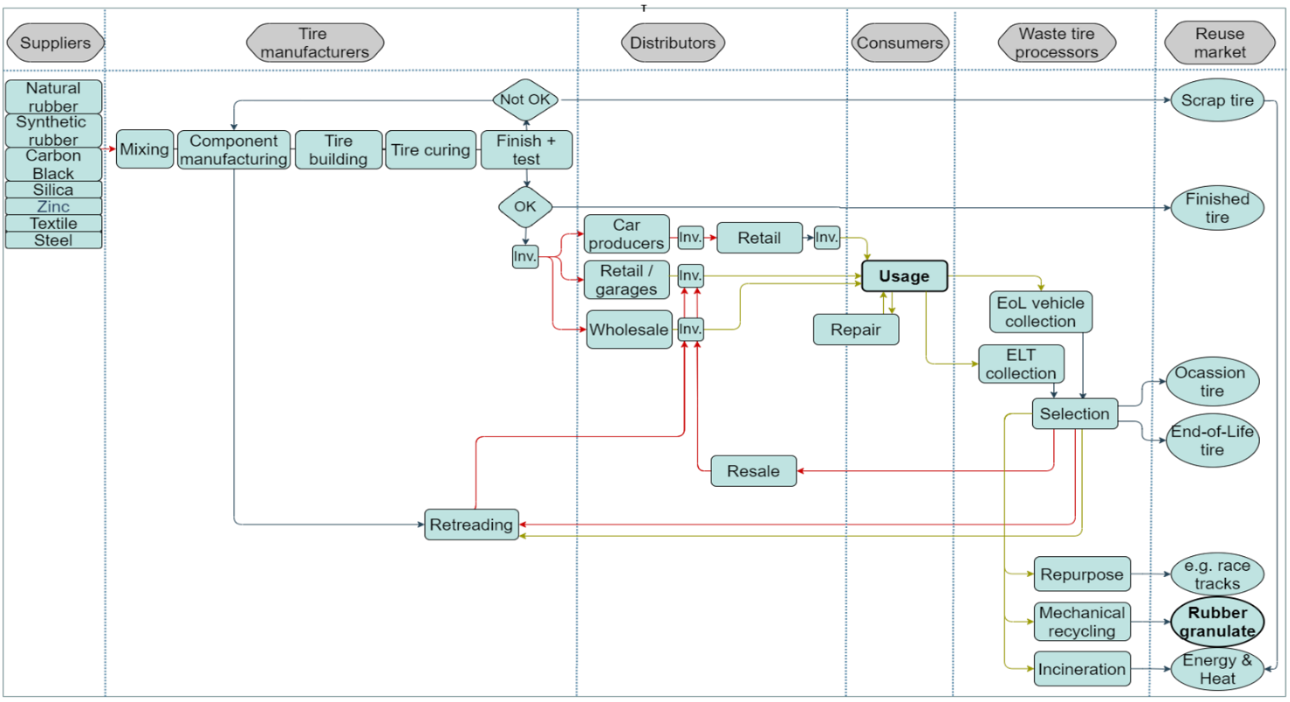

Figure 1. Tyre supply chain map. The supply chain is a global system, yet the presented tyre collection and End-of-Life processes are Dutch-specific. The rectangular boxes represent the processes, with the diamond shapes representing check processes. The boxes on the right side represent the different products that result from the processes on the left. The red arrows show the intercontinental or international streams, the yellow are regional or local streams and the blue are undefined or on-site. The shapes in bold are the processes from which microplastic emissions emerge

2.2 Identification and involvement of relevant key stakeholders

2.2.1 Methods

A stakeholder network analysis was performed, which is a strategy to examine and map the influence of individual actors, their interrelationships and the connectedness and clustering within the network as a whole (USAID learning lab, 2019; Zedan & Miller, 2017). The first step in performing such a stakeholder network analysis was to identify all actors that have an interest in relation to tyre microplastic emissions and categorize them into subsets. Finally, only the most relevant actors from the Dutch and European stakeholder networks were included. Secondly, the respective interest of each subset was formulated as well as their relation to tyre microplastics. Thirdly, the interrelations between stakeholders were defined, using the following relations:

- *Formal reportin*g: relationship between same-level authorities or between organizational and executing entities, e.g., formal reporting regarding agreements, legislation or commissions.
- *Trade relationship*: tyre-related trade of financial exchange between actors.
- *Non-financial suppor*t: a strong connection between entities that is based on shared goals rather than financial incentives.
- *Indirect influence*: no strong personal connection, but indirect involvement within a certain topic, e.g., collaboration in a bigger workgroup, lobbying or sharing knowledge.
- *Member-association relationship*: the relationship between an individual company and an association that represents the interests of that specific group.

Lastly, a visual representation of the result was made in the form of a stakeholder network map (Missonier & Loufrani-Fedida, 2014; USAID Learning Lab, 2019). The stakeholder network map was verified via written feedback from several stakeholders with a good understanding of the network.

Individual contact with a number of stakeholders was established and maintained during the study to obtain data and acquire insight into individual stakeholder interests. To facilitate this process, a sounding board group was set up to quickly receive feedback from experts and to make use of their stakeholder network. The sounding board consists of representatives from the tyre manufacturing industry, End-of-Life industry, academia and independent researchers. During the research period, one plenary consultation moment was organized in addition to contact moments with individual members of the sounding board group.

A stakeholder workshop was organized to validate the study's results, i.e., the supply chain map (Figure 1) and the quantified emissions (Figure 3). Thirteen participants attended the workshop, representing most stakeholder subsets. Unfortunately, no representatives from media and governmental institutions were able to join. The workshop was performed in the interactive online platform MIRO. The workshop started with an introduction to the research project and by the participants. This was followed by a brief discussion on microplastic-related challenges observed in the different sectors to learn more about each other's perspectives. Most time was spent on discussing the supply chain map and the quantified emission streams. Written feedback, a poll tool and questions were used to facilitate this process. The workshop ended with participants sharing possible mitigation measures and potential obstacles. Information with supporting figures was sent to the attendees beforehand.

Stakeholder subset	Interest	Relation to tyre microplastics
Suppliers	Making a living from high-quality raw materials.	No strong focus on TWRP/TWP.
Tyre manufacturers	Stay competitive in the market to maintain revenue. Improve products in terms of costs, performance and sustainability.	Dealing with pressure to produce tyres that emit fewer tyre microplastics, partly by funding research, organising knowledge exchange and contact with EU authorities. Prevent factual inaccuracies from causing image.
Distributors	Maintain sales with sufficient profit to make a living, while complying with legislation.	Stay up to date on tyre innovations and legislations, while meeting the wishes of the customer.
Consumers	Being able to buy safe and durable tyres for a good price. Some will value sustainability more than others.	With current tyre labels, it is difficult for consumers to compare tyres in terms of TWRP/TWP release. Might change (driving) behaviour or purchases to limit TWRP release.
End-of-Life industry	Maintain a stable inflow of tyres of a certain quality to make a living from the produced product.	Mechanical recycling is considered a circular option by the industry and is the most common route. This results in the need for a sales market for granulation.
Science	Provide scientific-sound knowledge to citizens, policy-makers and the industry.	Distinguishing facts from beliefs by filling in the data gaps around tyre microplastics.
Authorities	Provide and execute guidelines and legislation to protect both citizens and the environment.	Balancing economic and environmental needs based on the information available.

Builders & directors of roads	Provide safe roads that require minimal maintenance.	No strong focus on the role of asphalt on TWRP/TWP release. Innovating asphalt involves financial risks as builders are responsible for maintenance for the first number of years.
NGOs	Protect the environment and the health of citizens	Aims to limit the amount of tyre microplastic release as much as possible, though none have tyre microplastics as their main focus.
Reuse product market	Being able to buy safe and durable reuse products, such as granulate.	Need to manage new regulations and public opinions on the reuse product.
Media	Draw attention to topics that are considered socially relevant and/or that the public is interested in.	Broadcast specific journalistic items and highlight new research developments related to tyre microplastics.

Table 1. Identified stakes regarding the project per stakeholder subset

2.2.2 Results

Table 1 shows the different identified stakeholder subsets, including their interest and relation to tyre microplastic emissions. The stakeholder network map is shown in Figure 2. The network can be seen as having two planes, of which the Dutch network forms the lower national level and the European the higher overarching level. Between the planes, there are several points where the two levels are linked, e.g., by specific collaborations between actors, such as between the European Tyre Manufacturers Association (ETRMA) and the RecyBEM, but also through universities and research institutes which act on both levels. Furthermore, the national and European planes both have different objectives in relation to tyre microplastics. The European level aims to change the landscape through a top-down approach, e.g., by drafting and implementing European regulations around tyres, infill material and vehicle emissions, but also through developing universal testing and modelling methodologies. The Dutch level, on the other hand, has a strong national focus that also gives space for more direct initiatives, such as the Choose the Best Tyre campaign focused on responsible tyre purchase and maintenance. In addition to these two planes, several clusters can be distinguished within the network, such as a cluster related to the supply chain map and a cluster around governmental institutions. Specific initiatives or collaborations, such as the TWRP platform at the European level and the *Choose the Best Tyre* campaign at the Dutch national level, connect these clusters by bringing together individual stakeholders. Moreover, specific actors can be identified that form a main axis through which clusters are connected. At the Dutch level, the RecyBEM is an important central stakeholder by having different connections to a number of stakeholders and by being involved in several tyre-related initiatives in the Netherlands. Another central stakeholder is the ETRMA at the European level. The overall connectedness of the stakeholder network is relatively high due to existing initiatives and collaborations.

Both individual conversations and the stakeholder workshop revealed a shared feeling of urgency among stakeholders to reduce tyre microplastic release. This is also reflected in the high number of studies and research projects carried out by universities and research institutes (e.g., LEON-T, LABPLAS Project) and the activities initiated by the industry, such as funding research (e.g., Tyre Industry Project) and CSR Europe being the European TWRP platform's facilitator. Despite these shared ambitions, it appears as if stakeholders have different ideas on how to tackle the issue. Some of these ideas rely on technology, such as improved tyre labels and end-of-pipe innovations (e.g., the Tyre Collective), whereas others see a bigger role in societal change, such as interventions to reduce driving and the use of SUVs. The divergence in prioritized ideas is possibly the result of underlying interests that form the boundaries in which innovations or changes are considered desirable.

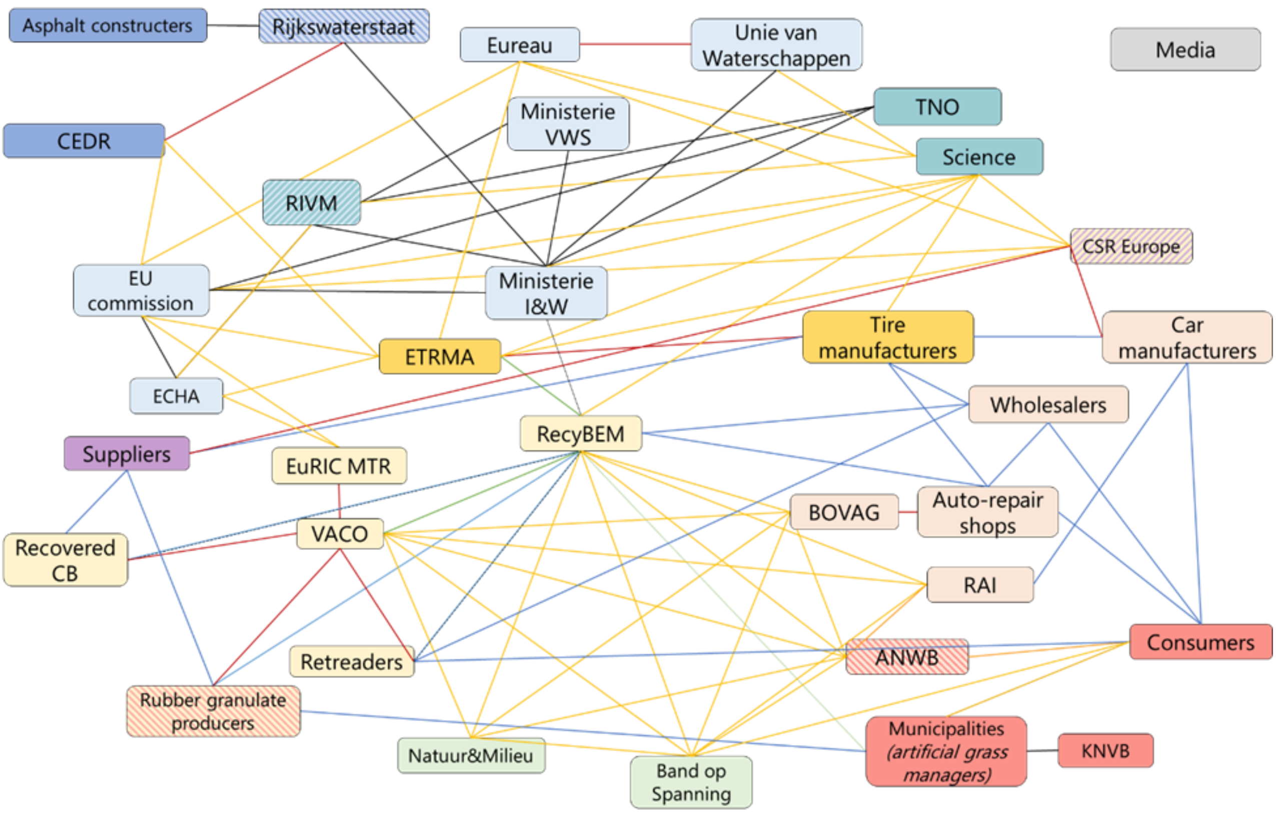

Figure 2. Stakeholder network map. Boxes represent stakeholders, where a different color is given to each subset. Purple refers to suppliers of raw materials; dark yellow to tyre manufacturers; light pink to distributors, dark pink to consumers of tyres and/or artificial turf infill; light yellow to actors in the End-of-Life industry; turquoise to science; light blue to authorities; dark blue refers to the road sector; green to NGOs. Media is shown in grey and as a separate unit due to its character as a communication channel. Striped boxes show actors that can be categorized into two subsets. The lines represent the (dominant) connection: black for formal reporting; blue for trade relationships; green for non-financial support; yellow for indirect influence; and red for member-association relationships.

2.3 Estimate of SMNP emissions

2.3.1 Methods

The tyre microplastics emissions were quantified based on a Material System Analysis (MSA) approach. MSA focuses on the flows of an individual material or natural resource within a system, including lifecycle-wide inputs and outputs, and is a subcategory of material flow analysis (OECD, 2008). The MSA methodology follows a similar procedure as that of a traditional material flow analysis. For each process, the material streams that relate to tyre microplastics emissions were tracked and quantified. Based on the mass of these material streams, the tyre microplastic emissions were quantified using an estimated loss value per mass unit. The initial emission streams from the supply chain were modelled over the environmental pathways to determine the environmental release. Lastly, a visual representation was made to present the results.

2.3.2 Mass flows

Data from the RecyBEM, the Dutch organization responsible for used tyre collection, and the European Tyre Manufacturers Association (ETRMA) was used to determine the number of tyres entering the model's system (ETRMA, 2022; RecyBEM, 2022). To calculate the weight in tonnes, an average weight of 8kg and 80kg for passenger car tyres and bus- and truck tyres was used, respectively (Continental, 2013). The passenger car tyre stock was calculated using data on the number of vehicles in use in 2021 (CBS, 2021). The bus and truck tyre stocks were estimated by multiplying the input of tyres by four representing the average lifespan of a tyre, i.e., 4 years (Hillenbrand et al., 2005). Of the collected passenger car tyres, 71% were mechanically recycled, 26% were sold on the reused tyre market, 1.1% was retreaded, 1.7% was incinerated and 0.2% was used for alternative purposes (RecyBEM, 2022). Of the collected bus and truck tyres, 20% was estimated to be retreaded, 26% to be reused and 54% to be mechanically recycled to rubber granulate (VACO, 23 September 2022). Rubber granulate was, subsequently, used in products, such as molded objects, safety and roof tiles and infill for artificial turf (RecyBEM, 2022).

2.3.3 TWP emissions

To calculate the TWP emissions emitted during the user phase, the Emission Factors (EF) (in mg/km) from Gebbe & Hartung (1997), Luhana et al. (2004) and ADAC (2021) were used. These three studies were selected as these are considered the most trustworthy studies (Mennekes & Nowack, 2022). The average weight loss percentage per tyre type was determined using a formula that included the Emission Factor, the average tyre weight and the average mileage per tyre's lifespan. An average mileage per tyre of 55.000 and 80.000 km for passenger car tyres and bus- and truck tyres were used, respectively (Boulter, 2005; GRPE, 2013). This resulted in an average weight loss of 14% over a tyre's lifespan, which is in line with the 10% to 30% weight loss found in the literature (Grigoratos & Martini, 2014; Wik & Dave, 2009). With an average lifespan of 4 years (Hillenbrand et al., 2005), the estimated weight loss was 3.5% per year per tyre.

TWP can be captured in asphalt, particularly very open asphalt (ZOAB) which covers the majority of the Dutch highways (Geilenkirchen et al., 2022). Its capturing capacity is a side effect of the asphalt's open pores primarily aimed to improve drainage. As the ZOAB asphalt roads are cleaned twice a year and the wastewater is disposed of properly, the captured TWP do not contribute to environmental emissions (Rijkswaterstaat, personal communication, 2 May 2022; Geilenkirchen et al., 2022). The part of the TWP that is not captured in the asphalt will either be transported to the roadside, due to wind, splash water and traffic-induced turbulence, or to the sewer system or surface waters, due to runoff (Baensch-Baltruschat et al., 2020; Verschoor et al., 2016). Another share of the emitted TWP is airborne, contributing to the particulate matter in the air. This fraction likely deposits outside the system's borders (Evangeliou et al., 2020; Kole et al., 2017) and is therefore excluded from the total emission calculations. As there are important differences in pathways between different types of roads, e.g., due to differences in asphalt and connectedness to the sewer, a distinction was made between urban and rural roads and highways.

The sewer system in the Netherlands consists of 66% of combined sewers and 34% of (improved) separate sewers (Liefting & de Man, 2017). In the combined sewer system, the household and industry wastewater is collected together with road runoff and treated in a central wastewater treatment plant (WWTP). In case of large precipitation events, the combined inflow can result in combined sewer overflows in which part of the wastewater could be discharged to surface waters without further treatment (Brombach et al., 2005). In separate sewer systems, the road runoff is collected separately from the household and industry wastewater, limiting the risk of combined sewer overflows. However, the untreated road runoff is often discharged directly to surface waters (Kole et al., 2017). The improved separate sewer system partly bypasses this problem by transporting the sewage water to a WWTP as long as there is capacity (Liefting & de Man, 2017).

2.3.4 Turf emissions

To determine the microplastic emissions from artificial turfs, the mass balance by Kole et al. (2023) was used. This study was used as it is one of the most extensive literature studies available. The emissions as a result of snow clearing were omitted, due to the limited snow days in the Netherlands. The yearly weight loss per m2 of turf was determined using the absolute weight loss per field per year and dividing it by the m2 per field, as provided by Kole et al. (2023). To extrapolate this to the entire Netherlands, it was estimated there were 2688 large turfs and 5052 small turfs in the Netherlands in 2021 (Hann et al., 2018; Oldenkotte, 2017), translating to a total of 2326 ha of artificial turf.

Part of the emitted infill particles will be prevented from reaching the environment, e.g., by collection of infill granules from clothes and shoes or by cleaning maintenance equipment (Løkkegaard et al., 2019). Emitted infill particles that are not captured will be either transported to adjacent soils or paved areas or to the sewer system, as a result of processes such as runoff, movement and housekeeping activities (Løkkegaard et al., 2019; Regnell, 2019). The distribution of the environmental pathways was based on Løkkegaard et al. (2019).

2.3.5 Results

Figure 3 shows the material streams of the MSA and the quantified emissions to different environmental compartments. It shows that in 2021 112,600 t/y of tyres entered the Dutch system, of which 67% are passenger car tyres. The tyre stock counted around 469,500 t/y in that year. Driving resulted in approximately 16,650 t/y of TWP emissions. The emissions from artificial turf in the form of infill granules were estimated to result in approximately 5,940 t/y. Hence, 74% of the initial emissions are caused by the user phase. From the generated emissions, approximately 40% was captured before release to the environment.

The airborne TWP fraction was estimated to be 0.5% for highways and 1% for urban and rural roads (Grigoratos & Martini, 2014; Janssen, 1996). On highways, it was estimated that 80% of the generated TWP is captured by the ZOAB asphalt, 18% ends up at the roadside and 2% is emitted directly to surface waters (Verschoor et al., 2016). On urban and rural roads, 40% of the generated TWP was estimated to end up at the roadside and 60% to be transported to the sewer system (Verschoor et al., 2016). For emitted infill particles it was estimated that 52% ends up in adjacent soils or paved areas, and the remaining share flows into the sewer system (Løkkegaard et al., 2019). Of the tyre microplastics that enter the sewer system, 22% infiltrate into the soil, 52% are captured by the combined sewer system and 26% by the (improved) separated sewer system. From the combined sewer system 8% is discharged directly to surface waters without further treatment, due to incorrect connections or overflows. The remaining portion is transported to the WWTP (Liefting & de Man, 2017). From the (improved) separated sewer system, 82% is released to surface waters without treatment. The remaining 18% joins the sewage from the combined sewer to the WWTP (Liefting E & de Man, 2017). Here, 88% is removed and captured in the sludge, after which it is incinerated. The remaining 12% is released to surface waters as effluent (Iyare et al., 2020; Liefting E & de Man, 2017; van Egmond et al., 2021).

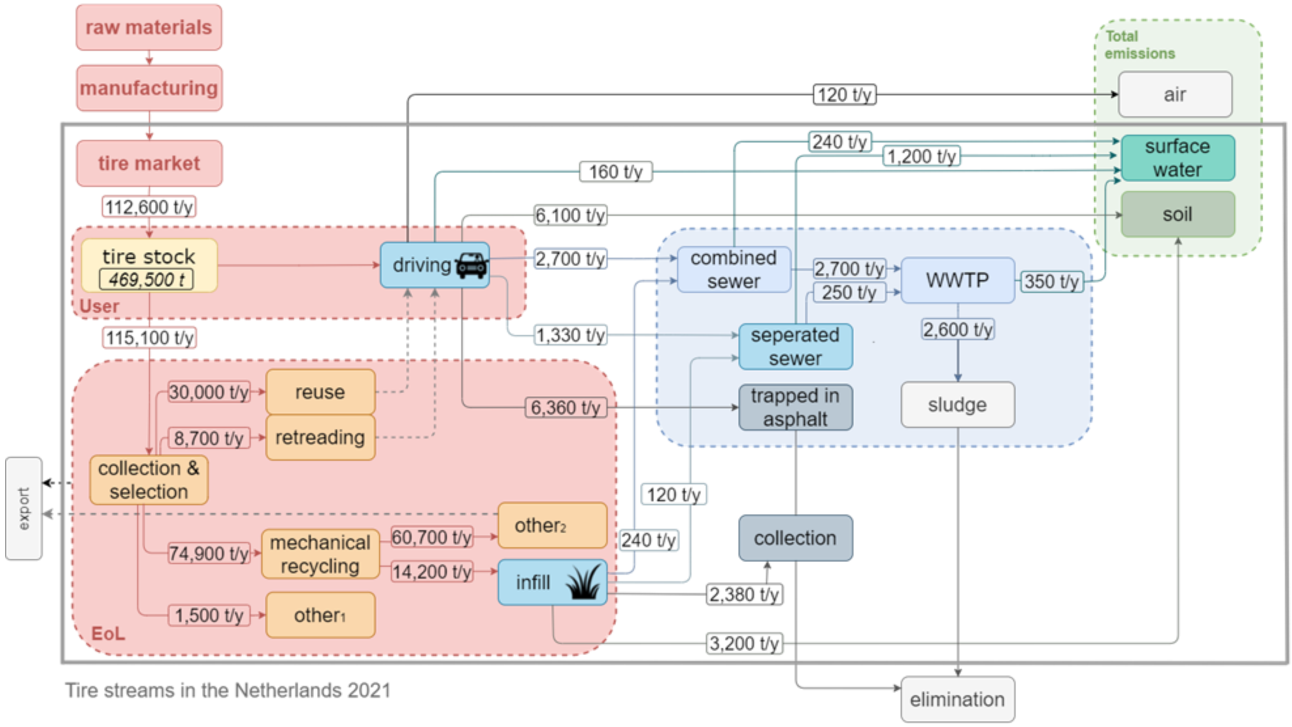

Figure 3. Material System Analysis for the Netherlands, 2021. Streams are shown in tonnes (kg) per year and are rounded. Other1 includes retreading, incineration and repurposing. Other2 includes agricultural mats, rubber tiles, molded objects, bedding construction for artificial turfs, rubber powder, rubber in asphalt and additional purposes.

Table 2 shows both the total mass flow of the estimated emission streams and the emission streams in kg per capita for the year 2021. That year the Netherlands counted 17.533.405 inhabitants (Worldbank, n.d.). As shown in the table, the majority of the tyre microplastics end up in the soil (83%) and 17% is received by surface waters.

Tyre microplastic emission streams in 2021	Mass flow (t/y)	Per capita (kg/cap/year)
Total initial release	22,590	1.29
Initial release as TWP from tyres (user phase)	16,650	0.95
Initial release as granules from infill (End-of-Life phase)	5,940	0.43
Total release to the environment	11,250	0.64
Release as TWP to the environment	7,880	0.45
Release as infill to the environment	3,370	0.19
Release to soil	9,300	0.53
Release to surface water	1,950	0.11

Table 2. Summary table of tyre microplastic streams for the Netherlands with 2021 as year of interest

2.4 Potential emission reduction measures

We identified a list of interventions to reduce tyre microplastics emissions based on a scan of the public literature and dialogues with stakeholders (see below). This is a preliminary list of interventions that will be further expanded and explored regarding feasibility and effectiveness in the next stage of the LABPLAS project. The interventions are organized in four main categories reflecting different stages of the tyre life cycle, i.e., (1) tyre design and manufacturing, (2) tyre use (driving), (3) End-of-Life (EoL) and (4) End-of-Pipe (EoP).

2.4.1 Tyre design and manufacturing

Improving the tyre design/composition and structure of tyres:

- Regulatory instruments in the form of substance bans and Best Available Technology (BAT).
- Economic instruments in the form of subsidies and taxes force companies to set new limits for the wear resistance of their tyres.
- Voluntarily instruments in the form of eco-design initiatives and voluntary commitments from actors.

Implement a legal threshold for tyre wear:

- Regulatory instruments, such as minimum standards, likely in combination with an economic instrument in the form of fines.

Include tyre wear in the tyre label (eco-labelling):

- Regulatory instruments in the form of certification schemes and labelling.
- Economic instruments in the form of subsidies and taxes.
- Voluntarily through enhanced sustainable decision-making of customers

Universal tyre wear test:

- Define definitions and terminology, to then standardize emission factors or methodologies of TRWP release.
- This can be obtained by mandating or encouraging the development of standardized and harmonized microplastic definitions. Set biomarkers to calculate TWRP in environmental samples. Economic by green procurement where companies are paid to develop methodologies.

2.4.2 Tyre use (driving)

Direct capture of generated TRWP:

- An example is the innovation by the Tyre Collective.
- Regulatory instruments through making use mandatory.
- Economic instruments through fines, subsidies and/or taxes.
- Voluntarily instruments were consumers or producers decide themselves to install it through enhanced awareness.

Improve tyre use and maintenance:

- Improve tyre pressure by behavioral change or technological tools, such as the smart tyre pump, PMS in older cars, or changing the settings of PMS.
- Improve correct wheel alignment by making it mandatory in the periodic vehicle inspection or using voluntary instruments, such as behavior.
- Regulate the use, tax or ban studded tyres or raise awareness to reduce unnecessary use could help reduce emissions from the use of studded tyres.

- Prohibit the use, implement fines for incorrect use or raise awareness to prevent/discourage the use of winter tyres in summer.

Eco-driving:

- Promotion by including it in driving lessons or implementing (and checking) speed limits.

Reduce the vehicle weight:

- Promote the use of light vehicles over SUVs by labelling, legal limit, subsidies, taxes.

Reduce driven kilometres:

- Economic: kilometer price (economic instrument) or promoting/subsidizing public transport.

Improve road surface:

- Road innovations aimed at reducing abrasion or include a filter to capture TRWP
- Improve road topography, such as reducing corners.
- Timely road management to repair the surface or improve capturing by road sweeping, snow removal and dust binding.

2.4.3 End-of-Life

Improve turf design (during the laying of the field):

- Improve the design of the carpet (tuft density, thatch zone, shock pads). Reduce the slope of the turf's surface. Can be obtained by green procurement.

Maintenance strategies and good housekeeping:

- Such as regular brushing and drag matting, installation of drainage slit traps, separate collection and treatment of turf runoff and to use dedicated storage areas for snow clearance or piling snow on the pitch. Installing brushing stations for shoe cleaning at entrance points through legal requirements, subsidies or taxes. The installation of physical barriers through legal requirements, subsidies or taxes.

Use alternatives to granulated turf.

2.4.4 End-of-Pipe

Interventions to treat or capture road runoff:

- Implement runoff treatment installations or drainage systems by installing sedimentation, gully pots, filter strips, infiltration chamber systems, bio-retention systems (such as swales) or road runoff treatment procedures. Can be obtained by regulatory instruments, such as environmental quality standards, Best available techniques, green public procurement. Economic instruments: Subsidies for improved stormwater management and/or road dust collection, Payments for Ecosystem Services.

Improve WTTP cleaning efficiency:

- Implementing additional cleaning steps or prevent the usage of sludge as artificial fertilizer.
- Regulatory instruments, such as Environmental Quality Standards (EQS); Best available techniques (BAT); wastewater treatments standards; Green public procurement;
- Economic instruments: Wastewater tariffs or taxes for improvements in wastewater, Subsidies for improved wastewater treatment.

Improve waste collection (not super applicable to NL):

- More stringent rules for the separate collection and management of used tyres. Economic instruments: Extended Producer Responsibility (EPR).

3 Case Study 2: Single-use plastics

3.1 Introduction

A single-use plastic (SUP) product are "a product that is made wholly or partly from plastic and that is not conceived, designed or placed on the market to accomplish, within its life span, multiple trips or rotations by being returned to a producer for refill or re-used for the same purpose for which it was conceived" (EU Directive 2019/904). Single-use plastics are goods that are made from fossil fuel-based chemicals and are disposed of right after use, mostly once and in short time after their use. Their use increased exponentially in the 70s when manufacturers replace paper, glass and other potentially re-usable and/or recyclable materials with plastic alternatives, because they were more durable and affordable. However, the short lifetime of SUP undermines one of the key properties of plastics, that is their longevity (Plastics Europe, 2020, 2021).

SUPs are the most common type of plastics produced and are difficult to recycle (Eriksen et al., 2019; Chen et al., 2021). The United Nations Development Programme (UNDP) stated that SUP products make around 86% of beach litter (UNDP, 2018) and the European Commission (EC) found that the 10th most common SUP items on European beaches represent about 50% of all marine litter in the EU. The 10th most common items found on sea shores are: (1) drink bottles, caps and lids; (2) cigarette butts; (3) cotton bud sticks; (4) crisp packets/sweet wrappers; (5) sanitary applications (sanitary towels, tampons, etc.); plastic bags; (7) cutlery, straws and stirrers; (8) drink sups and cup lids; (9) balloons and balloon sticks; and, (10) foods containers, including food packaging.

3.2 EU Legislation on SUPs

Legislation has been adopted worldwide to address this problem an also levies are charged (Xantos and Walker, 2017; Shnurr et al., 2018; Adeyanju et al., 2021). In addition, many scientific articles are published on Life Cycle Assessments (LCA) of plastic products (review in Nessie et al. 2022; dataset from PlasticsEurope https://plasticseurope.lca-data.com).

The EU approved in 2019 a pionneer legislation, EU Directive 2019/904, derived from the EU Plastic Strategy (European Commission, 2018) or SUPD (Single Use Plastics Directive). This directive focused on the 10 following products (Kiessling et al. 2023), selected for being the most common litter objects found on European beaches, which were also selected for having easily available alternatives (Addamo et al., 2017). An implementing regulation linked to the SUPD was approved in 2020 by the European Commission.

The banned products are the following:

- Cotton bud sticks
- Cutlery, plates, straws and stirrers
- Balloons and sticks for balloons
- Food containers
- Cups for beverages
- Beverage containers
- Cigarette butts
- Plastic bags (lightweight plastic carrier bags)
- Packets and wrappers
- Wet wipes and sanitary items

The Directive also covers oxo-degradable plastics. Oxo-degradable plastics are usually conventional polymers (e.g. Low-Density Polyethylene, LDPE) to which additives (chemicals) are added to accelerate oxidation and fragmentation of the material. They are neither bioplastic nor biodegradable plastics (see section 6). They may generate some confusion and a serious environmental and health problem, which will be explained in section 6 of this deliverable because it would be relevant for our case study, due to the use of this technique in some new SUPs and plastic bags, in particular.

For non-banned products in the SUPD, the focus is on prevention, through consumption reduction, marking and product design requirements and improved waste management.

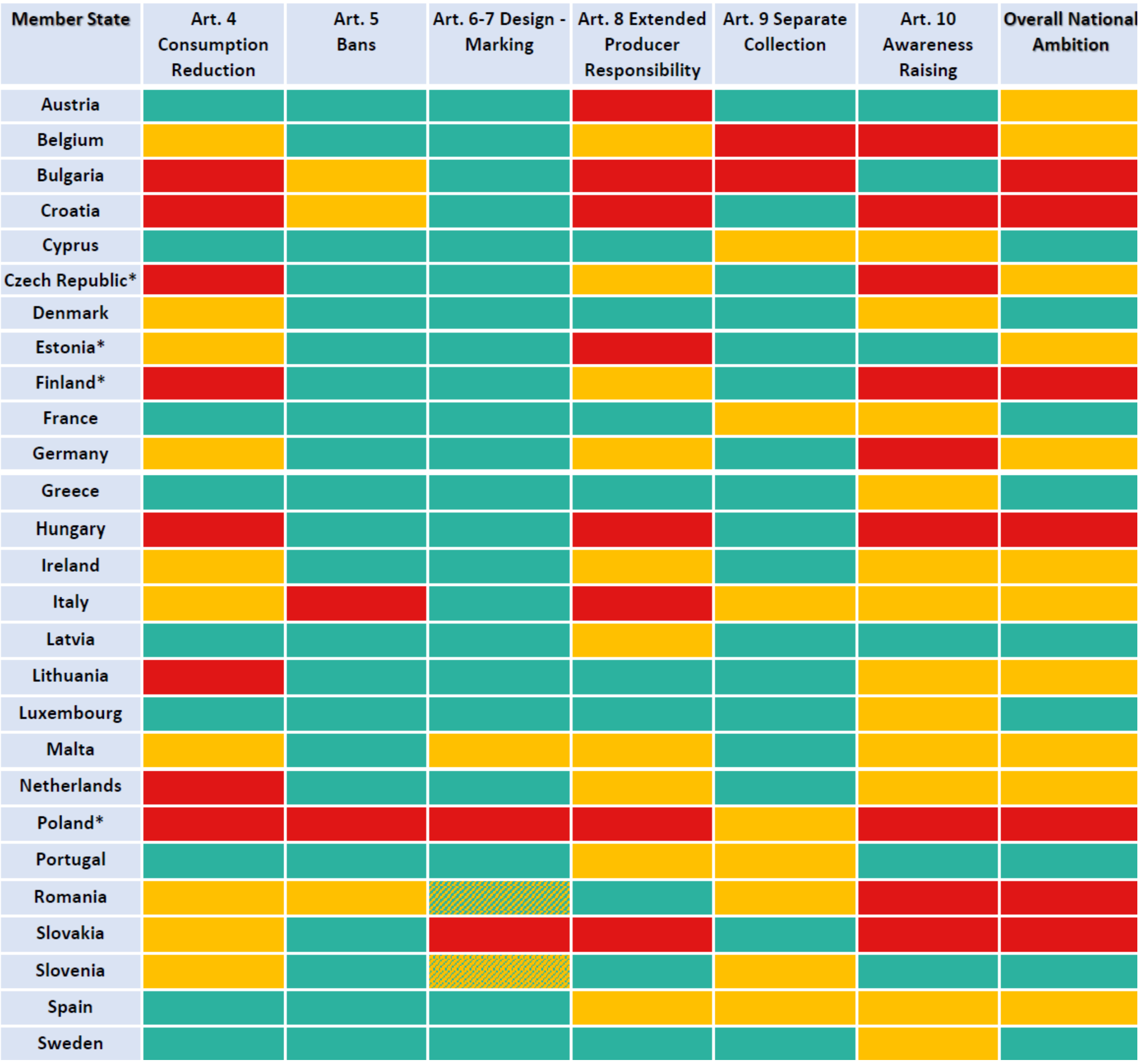

Figure 4. Implementation status of SUPD Directive per measure (Source: Rethink Platic, September 2022)

This 2019 Directive is being transposed to national regulations. Each member state should have transposed the directive into their national law before July 2021 to be operational by 31 December 2024. Rethink Plastic (2022), in a report on SUPD implementation, shows that three years after the adoption of the SUPD and one year after the end of the transposition period, most of the EU member states have now transposed the Directive and are already implementing the first batch of measures. However, the report highlights large differences among countries: some adopted ambitious measures to take up the challenge (i.e. France, Greece, Luxembourg, Sweden, Ireland, Cyprus or Portugal), but others show delays in implementing the Directive or are unambitious and had still not adopted all the measures needed, in the time the report was published, in September 2022 (Figure 4). Spain, for example, reported to the European Commission the transposition of the SUPD, through Law 7/2022, 8th April 2022, de *Residuos y Suelos Contaminados para una Economía Circular* (Waste and Polluted Soils for a Circular Economy) with a considerable delay and a lot of work still to be done.

3.3 SUP case study: Selection of products

Plastic bags can be divided into two categories based on their use: carrier bags and garbage bags. Carrier bags are found mainly in supermarkets, bookstores and clothing stores and they are the subject of most of the publications due to the recent bans worldwide (Nielsen et al. 2019).

A garbage bag (also named bin bag, rubbish bag, bin liner, trash bag or refuse sack) is a disposable bag used to contain solid waste. Most of them are useful to line the insides of waste containers to keep them sanitary by avoiding contact with the garbage. Usually, they are made of polyethylene (PE), a soft and flexible plastic with high resistance and strength. Trash bags of different thicknesses, colours and sizes are available and affordable. They are used in several places and areas including homes, markets, restaurants, schools, offices, commercial buildings, hospitals, industries, or agriculture, as they control the odour from waste, reduce toxicity and aid in sanitation.

Garbage bags are usually thicker than carrier bags because they must support a higher weight (López Gómez and Serna Escobar, 2021). There are various standards and regulations specifying the thickness of plastic bags for different purposes, including those from the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO). There are also specific regulations for regions and countries. In Europe, the European Plastics Converters (EUPC) offer information on the characteristics of plastic packaging and bags.

Martinho et al. (2017) stated that many consumers were used to using carrier bags as waste bags but, since the taxes and bans on these last ones, the consumption of garbage bags has increased and is expected to continue growing in the following years.

However, garbage bags are a type of SUP that is explicitly excluded from the 2019 Directive (COM, 2021 and section 4.6.2 of the 2019 Directive) and, also, of the recent regulations for packaging (Directive 94/62/EC or Packaging and Packaging waste directive, and amending Directives EU 2015/720, on Plastic Bags, and EU 2018/851).

As far as waste generation is increasing, (Eurostat, 2024) with 513 kg of municipal waste per capita in 2022 (500 kg per capita in 2004), 220 million tons in the EU (2 million tons more than in 2017), consequently, the purchase and use of garbage bags is expected to increase. The data (EEA, 2023) show a decrease in total waste generation per capita between 2010 and 2020, by 4,2% in the EU, with a similar trend for municipal waste. However, this decrease is recent (2018-2020) and coincides with the slowdown of the EU economy due to the COVID-19 pandemic. Predictions do not show a decline by 2030.

Thus, the second case study is focused on garbage plastic bags. They are commonly used products, well known by consumers (what makes the future analysis of preferences easier), and there are environmentally friendly substitutes (less fossil-based – hybrid origin, but biodegradable). Although garbage bags are excluded from the current European SUP Directive, they have the potential to cause the same environmental and health problems as carrier bags. This case study is designed and applied to serve as an example of analysis which may be applied to other SUP products currently excluded from the SUPD.

Table 3 summarizes the material, source, biodegradability and volume of the products selected. Although initially garbage bags of 50 l. were selected as the object of study, posterior results from Beiras et al. (2024), based on the methodology described in Beiras and López-Ibañez (2023) and Beiras et al. (2021), show that those large bags are quite different in composition and characteristics, and less common-used than smaller ones.

Product	Material	Source (bio/fossil)	Biodegradability*	Volume
Garbage bag	PBAT and PHA	Hybrid	Biodegradable	50 L
	PE	Fossil	Non-biodegradable	50 L
	Mater-bi (PET and polyester)	Hybrid	Biodegradable	10 L
	PE	Fossil	Non-biodegradable	10 L

Table 3. Selected products for SUP case study. Source: data from table 3 of D5.6 LCA Methodology to compare plastics.

Table 4 summarizes some degradation and ecotoxicity results. The results show that PE materials are non-toxic but also non-degradable and compostable materials show decaying mechanical properties but limited biodegradability and, in some instances, marine toxicity.

Description	composition	Biodegradation	Mechanical degradation	Ecotoxicity
		BOD28 (%C+)	60-d Strength at break MPa)	Seaurchin 1 g/L TU
PE materials				
Conventional PE trash sac (10 L)	PE	0.0	30.6*	< 1
Recycled PE trash sac (30 L)	PE, CaCO3	0.4	9.4	<1
Compostable materials				
Home compostable trash sac (30 L)	PBAT+starch	12.4	0	**2.41**
Compostable trash sac (10 L)	PBAT+starch+PLA	13.4	0	**5.24**
Industrial compostable trash sac (30 L)	PBAT+starch+PLA	15.6	0	**2.07**

*from a conventional (single-use, not recycled) PE carrier bag of the same thickness

Table 4. Comparison of biodegradability, mechanical degradation and ecotoxicity of trash sacs/garbage bags. Source: Beiras et al (2024)

In addition, D5.7 *LCA Report*, section 3 (*Comparative LCA for garbage bags*) offers a comparison of garbage bags made from different materials. For this case study, the results for low-density polyethylene (LDPE) and the industrial compostable polybutylene adipate terephthalate (PBAT) are relevant to define intervention measures. Conclusions for LCA on plastic bags show manufacturing of biodegradable garbage bags should be improved, due to the high impact values found in the PBAT manufacturing phase. Materials used in the production (amount, proportion) and the additives used, are key factors that producers may use to improve the environmental performance of garbage plastic bags.

3.4 Map of the supply chain

To map the supply chain of plastic bags, a methodology similar to that of car tyres was used. The supply chain operations reference (SCOR) model was used to describe and map the garbage plastic bag supply chain. The process is similar to case study 8.1., starting with the identification of stages in the supply chain, and then the processes inside each stage, representing the information visually, with connections among processes. Only material streams were included (avoiding information streams). All the information was obtained from published literature, found through web-based search engines about rubbish/garbage/trash/bin bags and linked to production, management, LCA, waste, supply-chain mapping, plastic supply chain and value chain analysis.

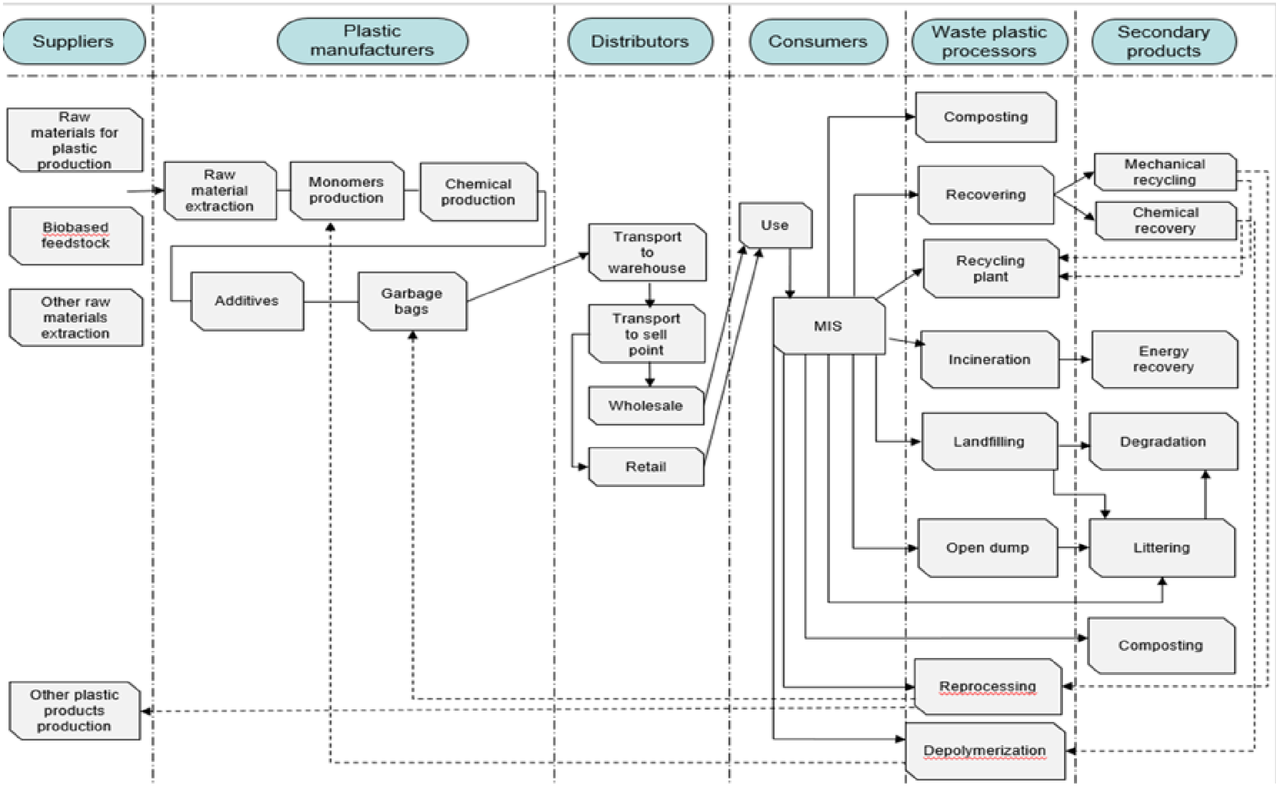

Figure 5. Plastic bags supply chain map

The supply chain map goes from providers of raw materials to disposal of these SUPs. The supply chain was organized into six stages: (1) suppliers of raw materials, plastic bag manufacturers, (3) distribution (wholesale and retail), (4) consumers, with special attention to end-of-life stages, that are, waste plastic processors (5) and secondary products (6). The map of the supply chain is a key issue to identify key stakeholders, which will be presented in 3.5.

3.5 Identification of relevant key stakeholders

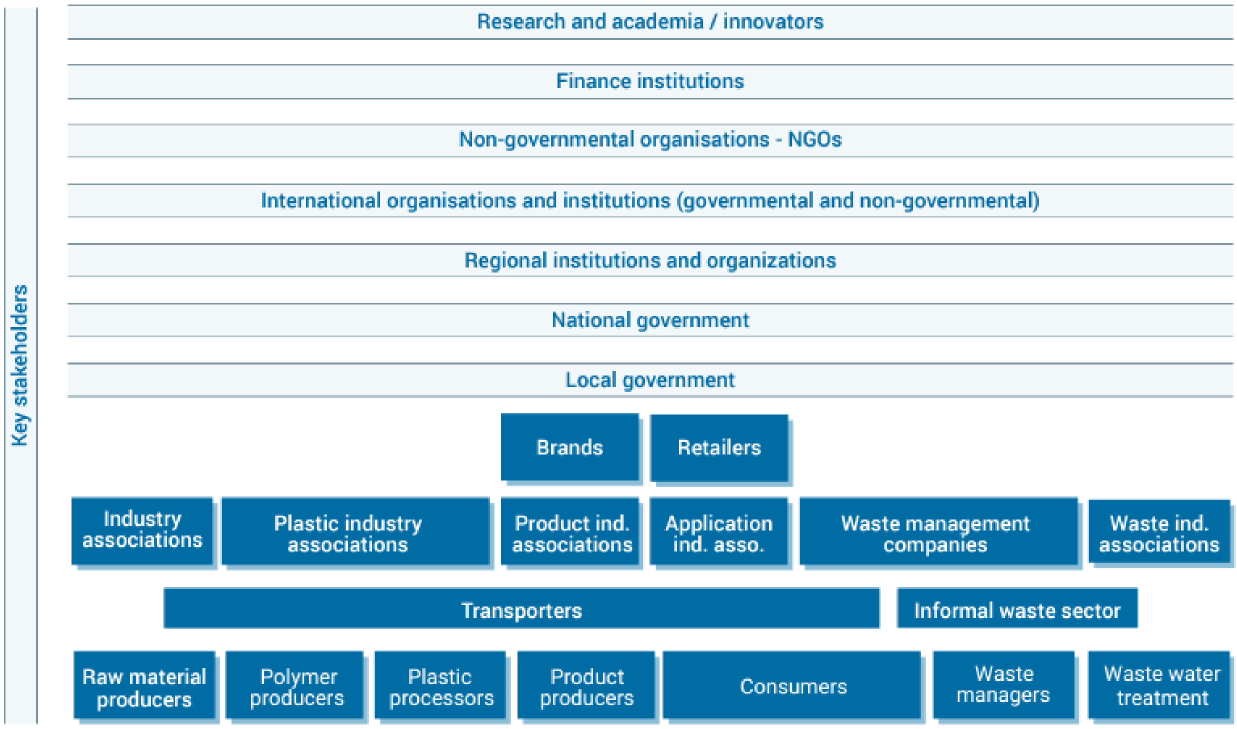

Figure 6. Overview of stakeholders/interest groups associated with each supply chain stage (UN Environment, 2018).

The supply chain map indicates the key stakeholders linked to each of the stages. Key actors are, clearly producers (both of raw materials, intermediate and final consumption products) and here, plastic industry associations, like PlasticsEurope, are relevant to participate in decisions regarding mitigation measures. Consumers, as final users of the products, have been introduced because they make purchase decisions and market choices among different available products, and after consumption, they decide the disposal strategy they prefer. They are the more relevant actors because they may also influence and put pressure on plastic producers based on their consumption preferences and choices, or through NGOs. It also includes International, National, Regional and Local governments, as responsible for the legal framework, and for the collection and treatment of municipal solid waste. These actors, different from the industry, can influence all parts of the plastic value chain and are transversal to the whole process.

The EU recommends, in “A European Strategy for Plastics in a Circular Economy” (EC, 2018), previous to the EU 2019 Directive, stakeholder involvement, including citizens and NGOs, as a key component in the transition to a circular plastic economy. Taking into account this requirement, Clausen et al. (2020) carried out a stakeholder analysis of active stakeholders within the regulatory microplastic debate, with identification, understanding of their interests and relationships and finally, using this information to evaluate the applicability of proposed measures. They use also the following definition of stakeholder, which we assume in this work: “*An individual or group influenced by–and/or with an ability to significantly impact (either directly or indirectly)– the European Union (EU) regulation of microplastics and which have actively participated in the regulatory debate*”.

Type	*Stakeholders/stakeholder sub-groups*	*Abbreviation*	*Group*	*Description/Examples*
Primary	Large Companies	L Companies	Large Companies	Consists of all companies with more than 250 employees.
	Small and medium-sized enterprises	SMEs	SMEs	All companies with up to 250 employees.
Secondary	European Oilfield Speciality Chemicals Association	EOSCA	ITA	Association that responds to regulatory requirements for approval of offshore chemicals and drilling muds.
	European Plastics Converters	EuPC	ITA	The trade association of the European plastics converting industry.
	International Association of Oil and Gas Producers	IOGP	ITA	The petroleum industry's global forum.
	International consumer NGOs	IC NGOs	International NGOs	E.g. the European Consumer Organisation (BEUC) and the Center for International Environmental Law (CIEL).
	International environmental NGOs	IE NGOs	International NGOs	Encompasses a range of NGOS including: Beat the microbeat; ECOS; Earthwatch Europe; ChemSec; ClientEarth; WWF, EEB and Greenpeace.
	International Pharmaceutical Excipient Council Europe	IPEC Europe	ITA	Global organisation that represents producers, suppliers and end users of excipients.
	National environmental NGOs	NE NGOs	National NGOs	National rooted environmental NGOs such as the Scottish Fidra and the German Nature and Biodiversity Conservation Union.
	National sport association NGOs	NSA NGOs	National NGOs	Consists of national and regional football associations e.g. Deutscher Fuβball-Bund (DFB)
	Other national NGOs	ON NGOs	National NGOs	National NGOs whose focus is not directly related to the environment. The group includes: Ellen McArthur Foundation; Breast Cancer UK.
	Regional authorities	RA	National authorities	Encompasses municipalities, regional councils and other local authorities.
	Researchers	Researchers	Academia and researchers	Includes scientists, college professors and researchers.
	Union of European Football Associations	UEFA	International NGOs	The administrative body for football, futsal and beach soccer.
	Arctic Monitoring and Assessment Programme	AMAP	International authorities	International organisation that implements components of the Arctic Environmental Protection Strategy.
	European Chemical Industry Council	CEFIC	ITA	Main European trade association for the chemical industry.
Tertiary	European Chemicals Agency (Including RAC and SEAC)	ECHA	International authorities	Responsible for managing REACH and includes the Committee for Risk Assessment (RAC) and Committee for Socio-Economic Analysis.
	European Environment Agency	EEA	International authorities	The EU agency that provides information on the environment.
	European Commission	EC	International authorities	The executive branch of the EU, including SAPEA.
	European Council	Ecouncil	International authorities	EU body that defines the political direction and priorities of the EU.
	European Food Safety Authority	EFSA	International authorities	EU agency that provides scientific advice and communicates on risks associated with food.
	European Parliament	EP	International authorities	The legislative branch of the EU, and the 751 elected members from the 28 member states.
	International Union for Conservation of Nature	IUCN	International authorities	International organisation working for use of sustainable nature resources in the field of nature conservation.
	National elected politicians	NEP	National authorities	Politicians in EU countries.
	National environmental governmental bodies (E.g. DK EPA)	NEGB	National authorities	These include national environmental protection agencies as well as forestry, conservation and other governmental environmentally-related bodies.
	National governments	NG	National authorities	Governments in Europe.
	Nordic Council of Ministers	NCM	International authorities	Body for intergovernmental cooperation of the Nordic Region.
	United Nations	UN	International authorities	Intergovernmental organisation responsible for maintaining peace, international relations and international cooperation. Includes UNEP, UNEA and WHO.

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Table 5. Stakeholders categorisation (Clausen et al., 2020)

The starting point for the identification of SUP plastics, and garbage bags in particular, was the article of Clausen et al., (2020), which presents a stakeholder analysis concerning the new microplastics regulation in Europe. Table 5 above is extracted from this article, which presents 28 groups of stakeholders. Their abbreviations, corresponding stakeholder groups and descriptions are included. Also, they include the categorisation of primary, secondary and tertiary. Clausen et al. (2020) define primary stakeholders as direct beneficiaries, primary production (industry) and consumers. Secondary stakeholders support or provide services to the primary stakeholders, and they are, for example, NGOs, researchers and local authorities. Finally, tertiary stakeholders include all governmental bodies, national authorities and international authorities. This is a means to ensure that stakeholders on all levels are included in the analysis.

Based on the supply chain map and the work of Clausen et al. (2020), examples of stakeholders of the different stages have been organized into four groups:

1. Producers (suppliers and plastic manufacturers). Primary stakeholders.
2. Distributors (secondary stakeholders).
3. Waste processors (secondary stakeholders). Secondary stakeholders.
4. Public institutions (tertiary stakeholders), NGOs, and research (secondary stakeholders).

The concrete list of stakeholders, grouped in those four groups, will be provided in the final report. These stakeholders will be consulted to test proposed policy measures to act in different stages of the supply chain to reduce the presence of plastics for SUP and garbage bags in the environment. The list is still alive and will be fed with other stakeholders during the duration of the project.

3.6 Conceptual Framework

To estimate emissions to the environment and propose intervention measures, some definitions should be introduced, moreover related to concepts usually misused by producers and misunderstood by consumers. Those are oxo-degradable, biodegradable and compostable plastics. The information presented in the section has been mostly obtained from Greendotbioplastics.com and European-bioplastics.com and is relevant to clarify concepts and detect some problems of information regarding substitute materials of PE.

Some products, including bags, are made from conventional plastics and supplemented with specific additives to mimic biodegradation. In truth, however, these additives only facilitate fragmentation of the materials, which do not fully degrade but break down into very small fragments that remain in the environment – a process that would be more accurately described by the term “oxo-fragmentation”. However, they claim to be “degradable”, “oxo-degradable”, “oxo-biodegradable”, or “oxo-fragmentable”, and sometimes even “compostable”, without providing any sort of proof for the claims made.

Oxo-degradable plastics quickly fragment into smaller and smaller pieces, called microplastics, but don’t break down at the molecular or polymer level like biodegradable and compostable plastics. The resulting microplastics are left in the environment indefinitely until they eventually fully break down.

No currently internationally established and acknowledged standard or certification process proves the success of oxo-degradation. Without verifiable proof or certification for the claim, the term “oxo-degradable” is just an appealing marketing term.

Biodegradability, compostability and oxo-degradability are often used interchangeably but are not synonymous, and the confusion may have serious implications for the disposal and treatment of products at the end of their life. Companies need to have information, understand and be honest about their products.

Bioplastics are plastics sourced from biomass at the beginning of their life (bio-based), metabolized into organic biomass at the end of their life (biodegradable), or both. Biodegradable plastics are a small subset of bioplastics. Biodegradation is the process of conversion of plastics into water, carbon dioxide and biomass over time with the help of micro-organisms. The biodegradability of a plastic depends on the chemical properties of the polymer. Bioplastics can be bio- or petroleum-based.

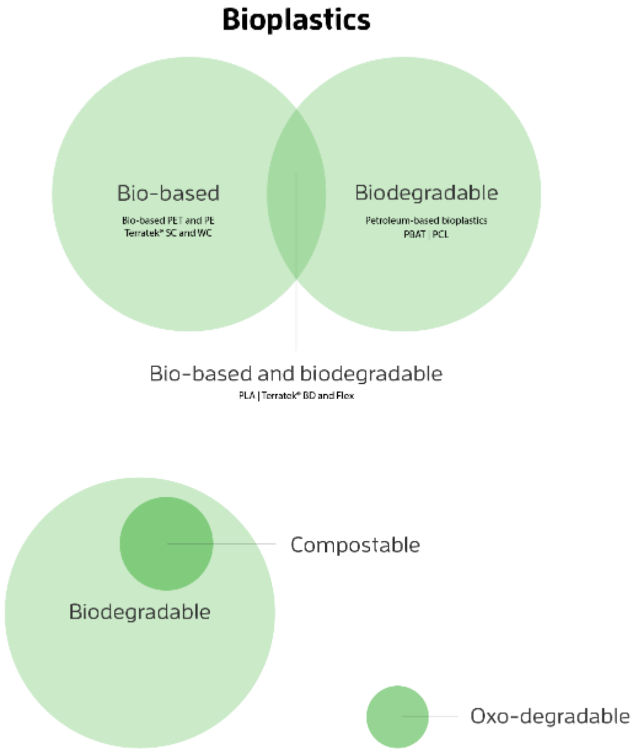

Figure 7. Bioplastics, biodegradable, compostable and oxo-degradable plastics. Source: Greendotbioplastics.com

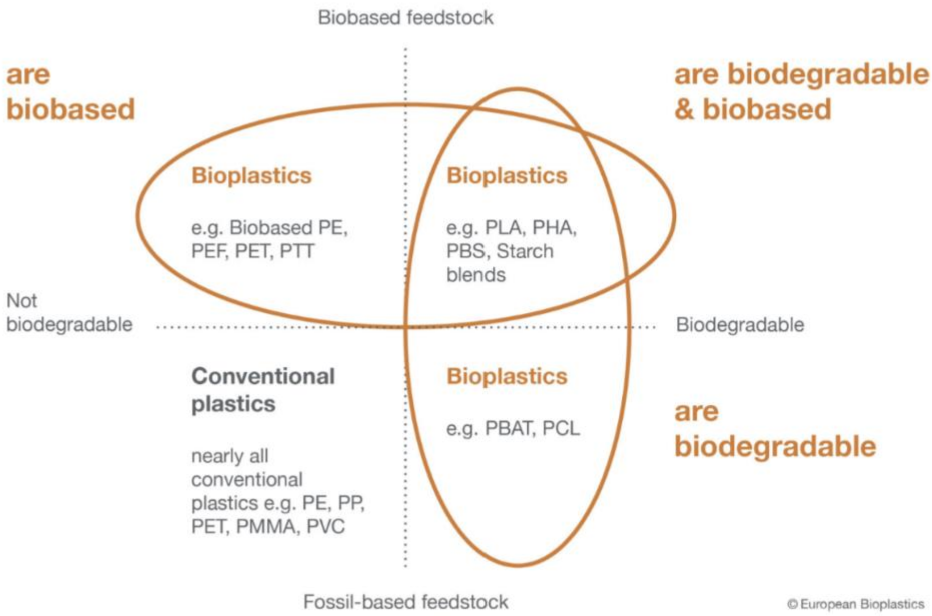

Figure 8. Conventional plastics vs. bio-plastics and their subtypes. Source: European-bioplastics-org

Compostable plastics are a subset of biodegradable plastics, defined by the standard conditions and time under which they will biodegrade. All compostable plastics are biodegradable but not the inverse. Moreover, compostable plastics must be certified by a third party, to adhere to international standards such as EN 13432 for biodegradation in an industrial composting facility. This is also important for the SUP case study because certified compostable materials must be disposed of in a designated composting facility, never at home. The reason is that they require higher temperatures for the materials to biodegrade (totally or almost totally) quickly enough. The waste of bio-based plastics must be managed like conventional plastics.

In the EU there are not enough industrial composting facilities (europeanbioplastics.org) which is an important shortcoming to incentivise the substitution of PE garbage bags for compostable ones. In some European countries (Austria, Belgium, Germany, Italy and the Netherlands) industrial composting is already well established but other countries still need to achieve an equivalent level. However, a separate waste collection system is fundamental to industrial composting.

3.7 Additives in single-use plastics (SUPs)

Single-use plastics (SUPs) often contain a variety of additives to enhance their performance, durability, and aesthetic appeal. Through the revision of several published works (Costa et al, 2020; Al-Malaika and Wilkie, 1999; Andrady, 2003; Biron, 2012; Chanda and Roy, 2007; Ebnesajjad, 2012, Kutz, 2011; Mark and Erman, 2013, Scheirs, 2000; Wypych, 2001) we can describe the different types of common additives used in the production of single-use plastics.

These additives play a crucial role in the production and performance of single-use plastics, tailoring their properties for specific applications and improving their usability in various conditions. However, some have proved effects on the environment and health as shown in Table 6.

Additive	Objective	Risks	Selected studies for risks
Plasticizers	Flexibility and workability. Ex. phthalates and adipates.	Plasticizers, particularly phthalates, can leach into the environment, causing endocrine disruption in wildlife and humans. They are persistent and can bioaccumulate.	Rahman, M., & Brazel, C. S. (2004). The plasticizer market: An assessment of traditional plasticizers and research trends to meet new challenges. *Progress in Polymer Science*, 29(12), 1223-1248. Staples, C. A., et al. (1997). The environmental fate of phthalate esters: A literature review. *Chemosphere*, 35(4), 667-749.
Stabilizers	Prevent degradation from heat, UV light, and oxidation. Ex:UV stabilizers, antioxidants, and heat stabilizers like calcium stearate and zinc stearate.	Some stabilizers, like lead and cadmium compounds, are toxic to aquatic life and can persist in the environment, leading to bioaccumulation and potential human health risks.	Fergusson, J. E. (1990). *The heavy elements: Chemistry, environmental impact, and health effects*. Pergamon Press.
Colourants	Add color. Ex. Titanium dioxide for white.	Certain colourants can be toxic and carcinogenic. They may leach into soil and water, affecting ecosystems and potentially entering the food chain.	Davis, S. N., & Wilkerson, C. L. (1998). Environmental considerations of dye pollution. *Journal of the Society of Dyers and Colourists*, 114(7-8), 250-254.
Fillers	Improve mechanical properties and reduce production costs. Ex: calcium carbonate, talc, glass fibres.	Fillers like calcium carbonate and talc are generally considered inert, but mining and processing can cause significant environmental disruption, including habitat destruction and dust pollution.	Wypych, G. (2016). *Handbook of fillers* (4th ed.). ChemTec Publishing.
Flame retardants	Reduce flammability. Ex: brominated flame retardants, antimony trioxide, phosphorus compounds.	Brominated flame retardants are persistent organic pollutants (POPs) that can bioaccumulate, potentially causing endocrine disruption and neurodevelopmental issues.	de Wit, C. A. (2002). An overview of brominated flame retardants in the environment. *Chemosphere*, 46(5), 583-624. Alaee, M., et al. (2003). An overview of commercially used brominated flame retardants, their applications, their use patterns in different countries/regions and possible modes of release. *Environment International*, 29(6), 683-689.
Antimicrobial agents	Prevent the growth of bacteria and fungi. Ex. Silver ions, triclosan.	Antimicrobials like triclosan and silver nanoparticles can lead to antimicrobial resistance and toxicity to aquatic organisms.	Daughton, C. G., & Ternes, T. A. (1999). Pharmaceuticals and personal care products in the environment: Agents of subtle change? *Environmental Health Perspectives*, 107(Suppl 6), 907-938. Benn, T. M., & Westerhoff, P. (2008). Nanoparticle silver is released into water from commercially available sock fabrics. *Environmental Science & Technology*, 42(11), 4133-4139.

Antistatic agents	Reduce static electricity buildup. Ex. Quaternary ammonium compounds, ethoxylated amines.	Quaternary ammonium compounds used as antistatic agents can be toxic to aquatic life and are known to persist in the environment.	Ying, G. G. (2006). Fate, behaviour and effects of surfactants and their degradation products in the environment. *Environment International*, 32(3), 417-431.
Lubricants	Reduce friction during processing. Ex. Stearic acid, polyethylene waxes.	While generally less toxic, certain lubricants can still cause environmental harm through bioaccumulation and persistence, particularly in aquatic environments.	Wypych, G. (2013). *Handbook of lubricants*. ChemTec Publishing.
Blowing agents	Create foam structures in plastics Ex. Azodicarbonamide, pentane.	Some blowing agents, particularly CFCs, are known to deplete the ozone layer and contribute to global warming. Alternatives like hydrocarbons can still have significant environmental impacts.	Andersen, S. O., et al. (2012). *The Montreal Protocol: Progress, challenges, and perspectives*. Ambio, 41(1), 91-98.
Processing aids	Improve de processability. Ex. Fatty acid amides and silicone oils.	Processing aids can be toxic to aquatic life and may persist in the environment, leading to long-term ecological impacts.	Goodship, V. (2007). *Introduction to plastics recycling*. Elsevier.
Impact modifiers	Enhance the toughness and impact resistance. Ex. Butadiene, rubber, ethylene propylene diene monomer (EPDM).	These can leach out of plastics and cause environmental contamination, potentially leading to toxicity in aquatic organisms.	Al-Malaika, S., & Wilkie, C. A. (Eds.). (1999). *Additives for plastics*. Springer.
Nucleating agents	Control de-crystallization, and improve clarity and mechanical properties. Ex. Sodium benzoate, talc.	Generally considered less harmful, but their environmental impacts can still be significant, particularly during the manufacturing process.	Karger-Kocsis, J. (Ed.). (1995). *Polypropylene: Structure, blends and composites*. Chapman & Hall.

Table 6. Additives and their risks

3.8 Emissions of SUP plastics

In the 1970s-1980s decade, plastic use, including plastic bags, began to rise significantly, replacing paper bags. In the 1990s, increased awareness of plastic pollution led to more data collection. In this century, the global production of plastics continued to rise significantly with more robust data collection and reporting by environmental agencies. Despite the increasing amount of information available, data on emissions specifically from garbage bags is limited. We will focus on plastic bag data, when available, and on SUP data in general, when no access to plastic bag data is possible.

According to a study by Geyer, Jambeck, and Law (2017) for the U.S.A., approximately 8.3 billion metric tons of plastic have been produced since the 1950s, with a significant portion ending up in landfills or the natural environment. The United States Environmental Protection Agency (EPA) 2020 report on municipal solid waste indicates that plastic waste generation was about 35.7 million tons, with a recycling rate of only 8.7%. Also, EPA states that in 2020, approximately 4,2 million tons of plastic bags, sacks and wraps were generated in the municipal solid waste stream in the U.S. alone. Recycling rates for plastic bags have historically been low. The EPA reported a recycling rate of around 10% for plastic bags and wraps.

Figure 7 illustrates the trends in SUPs and plastic bag production, from 1970 to 2022 for Europe. The total production of SUPs in Europe increased from 2 million tons in 1970 to 42 million tons in 2022. Plastic bag production (in million tons) has shown a steady increase over the past 52 years, rising from 200.000 tons in 1970 to 4.2 million tons in 2022. This increase reflects the growing demand for plastic bags in various sectors, despite efforts to reduce plastic usage.

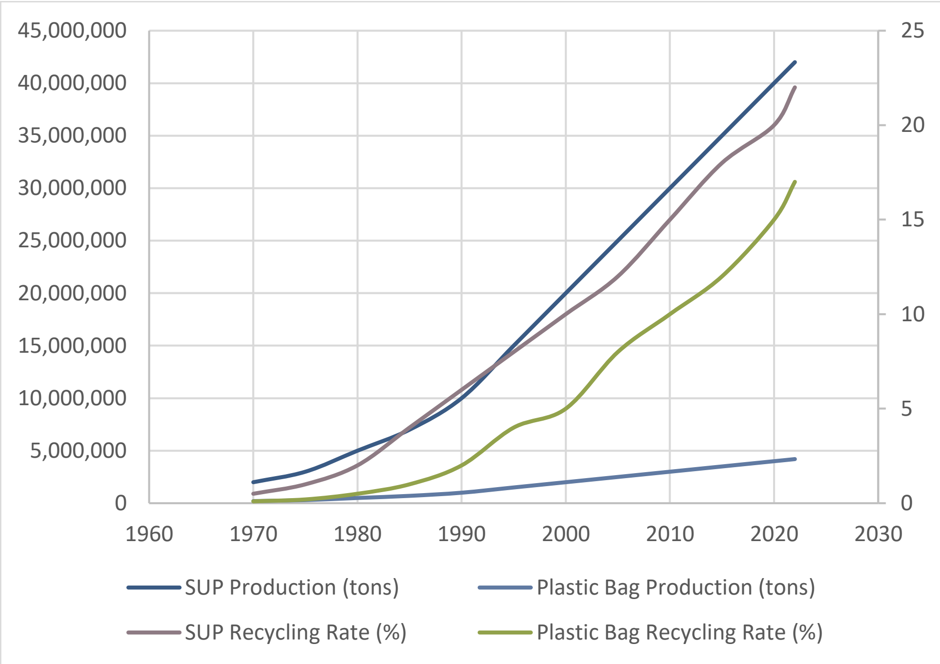

Figure 9. Plastic bag production, recycling rate for plastic bags and ocean waste in Europe (1970 – 2020). Source: data from EEA (2020, 2021), PlasticsEurope (2020), European Commission (2018) and UNEP (2021)

The figure shows the recycling rate for SUPs and plastic bags in Europe. The recycling rate for plastic bags specifically is generally lower than for plastics overall due to contamination and collection challenges, and this could be a bigger problem for garbage bags. SUPs recycling rate has increased from 0,5% in 1970 to almost 22% in 2022. For plastic bags, the percentage is lower, rising from 0,1% to 17% in the same period (European Commission, 2018). This indicates enhanced efforts and initiatives to recycle plastic bags, although the rate is still relatively low compared to the total production. The increase in recycling rates can be attributed to EU Directives and national policies aimed at improving recycling infrastructures and practices.

Finally, the contribution of SUPs to ocean waste is a significant concern, but specific data for plastic bags or even for SUPs is harder to find as most studies focus on total plastic waste. Based on several studies, emissions from SUP to oceans in Europe have been summarized in the following table (note that different sources and methodologies may differ) but it shows some figures that may illustrate the gravity of the problem. The data shows an increasing trend from 2010 to 2022, reflecting the growing environmental challenge of managing plastic waste. The sources for data are official reports from European and global organizations that monitor and report on the environmental impacts of plastic pollution.

Year	SUP Emissions to Oceans in Europe (tons)	Source
2010	500,000	European Environment Agency (EEA)
2015	600,000	UNEP (2021)
2020	700,000	EEA (2020)
2021	720,000	European Commission (2018)

Table 7. Estimated SUP emissions to oceans in Europe

3.9 Prevention/mitigation measures for SUPs

To reduce emissions of SMNPs to the marine environment, this case study aims to act on domestic-used conventional (PE) garbage bags, reducing their use, and increasing the use of compostable garbage bags, acting in the production, consumption and end-of-life stages of the supply chain.

3.9.1 Production/manufacturing of garbage bags

- More research on the generation of microplastics and potential impacts (biodegradability ecotoxicity), considering their composition (materials, additives) and way of release/treatment. As a result, a robust comparative analysis of different types of bags will be achieved.
- Change to industrial compostable garbage bags must be institutionally/legally supported but previously some R+D+I (Research, Development, Innovation) on them is needed:
  - Research and innovation to improve the design of compostable garbage bags to achieve a higher resistance, to make them more competitive/substitutive of PE bags.
  - Research on Eco-design, to improve biodegradation and lower ecotoxicity of compostable garbage bags. This could include not only industrial compostable bags but also home compostable ones.
- Create (or incentivise the use of existing) official, third-party, certification and labelling schemes, based on standardized methods (like EN 13432) for compostable (or other biodegradable alternatives) to PE bags.
- Avoid confusing industrial "green" claims about the biocharacteristics of garbage bags (e.g. oxo-degradable vs biodegradable).

3.9.2 Use/Consumption

- Encourage responsible consumption to diminish domestic waste generation, and consequently, the use of garbage bags.
- Economic incentives:
  - compulsory pay-for-generation schemes for home waste.
  - taxes on more environmentally damaging materials and additives.
- Information and awareness campaigns to the consumers to substitute conventional PE garbage bags with (certified and improved) compostable ones.
- Legal framework on waste that bans the use of environmentally damaging bags and encourages/makes compulsory the use of alternative compostable bags (always depending on the state of the research on alternative production methods).

3.9.3 End-of-Life (EoL)

- infrastructures, with public funds, to increase the number of industrial composting facilities and separate waste collection systems.
- a legal framework to avoid confusing industrial “green” claims about the biocharacteristics of garbage bags. Regulation is needed to avoid confusing bio and degradability characteristics. Consumers should have clear information when making purchasing decisions and they must know how to manage different materials at their end-of-life.
- D8.2 *Report describing the effectiveness of emission reduction measures of MNP for the two case studies, providing a general guideline on how to assess the effectiveness in collaboration with stakeholders,* due on M44 (Jan 2025), will present emission reduction measures for both case studies."

D8.2 *Report describing the effectiveness of emission reduction measures of MNP for the two case studies, providing a general guideline on how to assess the effectiveness in collaboration with stakeholders,* due on M44 (Jan 2025), will present emission reduction measures for both case studies."

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