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Plastics and biodiversity – Impacts of plastics on biodiversity and ecosystems

Authors:
Ive Vanderreydt (VITO), Pieter Willot (VITO), Jens Günther (UBA), Elvira Borgman (NORION), Anna Tenhunen-Lunkka (VTT), Tobias Nielsen (EEA)

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Summary

The report examines the, often overlooked, negative impacts of the plastic value chain on biodiversity and ecosystems. It highlights the pervasive threat plastics pose throughout their lifecycle—from resource extraction through production, use, and waste management—and emphasises the urgent need for a shift toward circular and biodiversity-friendly practices in plastics management to mitigate these adverse impacts.

Plastic production and consumption in Europe are substantial and projected to increase, intensifying pressure on the environment and biodiversity. Despite positive trends in plastic circularity, such as enhanced recycling capacity and reduced plastic waste exports, progress is slow, with significant challenges persisting across the entire value chain.

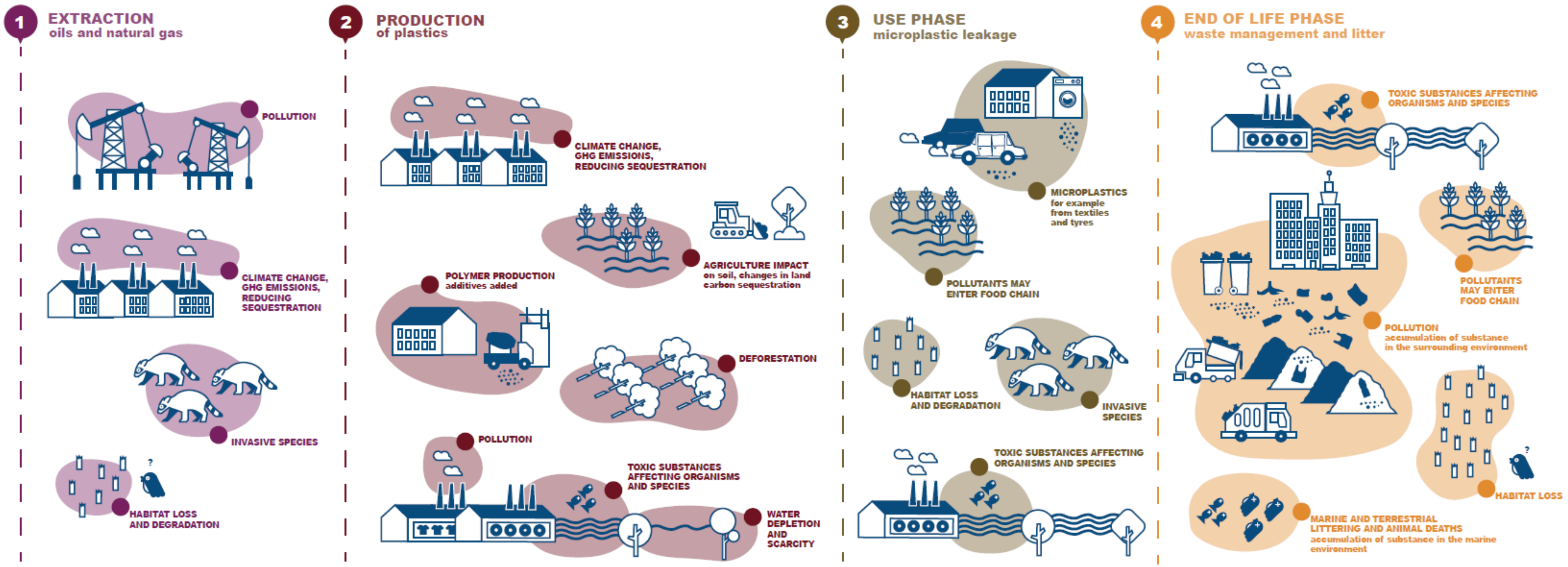
Images of plastic pollution in nature have become familiar, illustrating the widespread and persistent presence of plastics, their various forms of contamination, and their profound ecological and health impacts. However, hotspots of biodiversity impact affected by the plastics value chain are not limited to end-of-life waste management issues. They occur throughout the entire lifecycle, beginning with resource extraction. Both fossil and renewable resource extraction for plastic production can cause significant biodiversity loss through habitat destruction, pollution, and the introduction of invasive species. Additionally, microplastics from sources such as paints, pellets, textiles, and tires are major pollutants affecting terrestrial, freshwater, and marine environments. These pollutants pose physical and chemical threats to organisms and ecosystems.

While resource extraction for plastic production has a more direct and immediate impact on biodiversity through habitat destruction and pollution (of air, land, water), plastic leakage to the environment has long-term and pervasive effects on ecosystems. Both are critical issues that need to be addressed to protect global biodiversity.

Envisioned pathways toward circular plastics emphasize smarter use, increased circularity, and renewable materials. These are crucial tools in mitigating the negative impacts of plastics on biodiversity. Smarter use involves reducing unnecessary plastic consumption, redesigning products, and extending product lifespans to decrease raw material demand and mitigate related biodiversity impacts. Increased circularity focuses on longer product lifespans, greater reuse, and improved recycling and waste management systems to reduce reliance on virgin resources and prevent plastic pollution. Promoting bio-based plastics can reduce fossil fuel dependency but requires careful balancing to avoid biodiversity impacts from land-use changes and pollution.

In addition, addressing these impacts requires integrated approaches to environmental management, recognising the interconnectedness of biodiversity loss, climate change, and pollution.

Biodiversity impacts across the plastic value chain



1. Introduction: plastics and biodiversity

To mitigate the triple planetary crisis (referring to pollution, biodiversity loss, and climate change), a drastic change in our current production and consumption system is needed to safeguard human health, well-being, and prosperity for present and future generations. One focus area with this respect is plastics. (Villarrubia-Gómez et al., 2024).

When it comes to assessing the impacts of EU plastics production and consumption most studies have focused on plastics pollution and littering, while a few have assessed climate impacts (cf. (ETC WMGE, 2021a)). Very few, however, have considered the impacts on biodiversity (Schmidt et al., 2024). This report aims to improve the understanding of links between different phases of the EU plastics value chain and their impact on biodiversity, and provide insights to inform future discussions on the potential (and limitations) of a more circular plastics system to mitigate its negative biodiversity impacts.

The scope is the EU plastics system, covering the entire plastics lifecycle including production, use and end-of-life stages, including pathways for circular plastics (such as smarter use, increased circularity and renewable materials).

This report continues the EEA/ETC's work on the impacts of plastics on our environment and builds on previous EEA/ETC's reports, such as an overview of multiple environmental problems (Plastics, the circular economy and Europe's environment), on climate change (Greenhouse gas emissions and natural capital implications of plastics), pollution (Zero pollution cross-cutting story on plastics), marine (plastics) litter (From source to sea), from plastics used in textiles (Plastic in textiles).

This report complements these EEA/ETC by focusing on the impact of plastics on ecosystems and biodiversity. The policy context for this task includes the continued development of the CEAP and its focus on key value chains.

Plastic consumption in Europe is high and expected to grow, contributing significantly to environmental pollution and climate change through resource extraction, pollution, marine litter, microplastics, and GHG emissions. There are positive trends on circularity of plastics, including increased recycling capacity and reduced plastic waste exports, yet the pace is slow.

Europe faces high levels of plastics consumption, which are expected to grow in the future, intensifying its negative impacts on pollution, waste generation and climate change (OECD, 2022). The total plastics consumption in 2020 by end-users in the EU27+3 was 56.5 million tonnes, which is equivalent to an annual 107 kg/capita of which most will become waste after a short lifetime. The majority of plastics is used for packaging, followed by building and construction; automotives; electoral and electronic appliances; houseware, leisure and sports; agriculture, farming and gardening; and textiles (Figure 1). In 2020, around 30 million tonnes of post-consumer plastic waste were collected in EU27+3 (ETC CE, 2024d).

In general, the relatively low cost of fossil feedstock, coupled with the diverse functionality of plastic as a material, has lead and is continuing to lead to ubiquitous and growing global supply and demand for plastics (ETC CE et al., 2023).

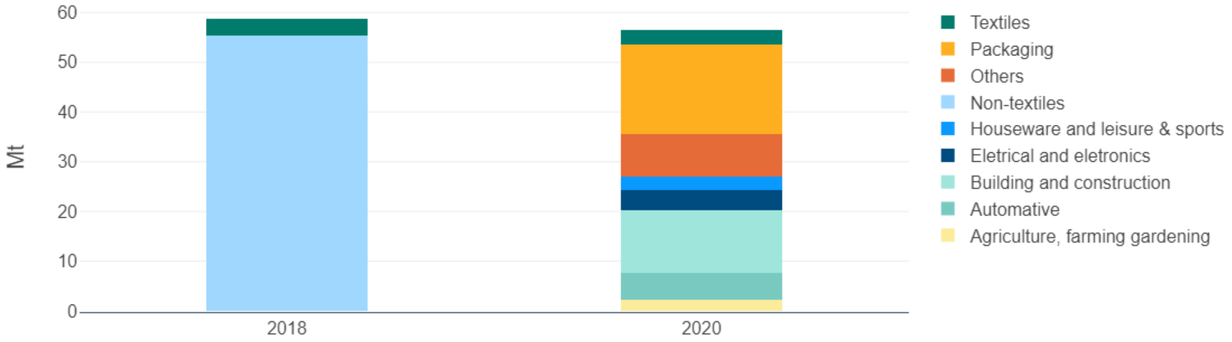


Figure 1. Total plastics consumption in the EU

In the EU, 99 % of recycling capacity is mechanical recycling; the total mechanical recycling capacity within the EU has increased from 2 million tonnes (1996) to 12.5 million tonnes (2022) (ETC CE, 2024a) (PRE, 2024). This represents an almost six-fold increase reflecting the investments made by the recycling industry towards more plastic recycling, possibly triggered by EU legislation entering into force in the last decade calling for more separate collection of plastics for recycling. This shift suggests potential improvements in the recyclability and quality of plastic waste exports, although further investigation is needed to understand the underlying drivers (ETC CE et al., 2023) (ETC CE, 2024b). Elaborating on the microplastics, the European Commission (DG ENV, 2023) estimates that 0.7-1.8 million tonnes of microplastics from paints, tires, pellets, textiles, geotextiles and detergent capsules were unintentionally released into the environment in the EU in 2019. (European Commission (DG ENV), 2023)

Efforts to increase circularity include circular product design, longer use, reuse, improved waste collection and recycling infrastructure, and the development of markets for recycled plastics. However, achieving full or even high-level circularity requires close collaboration among stakeholders along the value chain and a shift toward circular business models (ETC CE et al., 2023). While efforts are underway to improve the circularity of plastics production and consumption in Europe, significant challenges persist. Addressing these challenges requires a coordinated approach involving policymakers, industry stakeholders, and consumers to transition to a more sustainable and circular plastics system. Further research and development are needed to overcome technical and logistical barriers and achieve the long-term goals of a circular economy for plastics. Furthermore, data gaps and difficulty of finding comparable data limits the full understanding of the fate of plastics in the EU.(Günther et al., 2023).

2. EU plastics lifecycle and biodiversity impacts

The value chain of plastic (containing) products (Figure 2) consists of several consequential steps which start from the extraction of fossil and biobased resources that are processed into plastics.
Converting these plastics into components and products makes them ready to be put on the market.
After the products has served their function, different strategies can be followed to treat the plastic waste.
Policy actions aim to prevent or move away from non-circular pathways such as incineration, landfill and leakage to the environment towards circular pathways that recover the product, material or feedstock so that it can be used again.

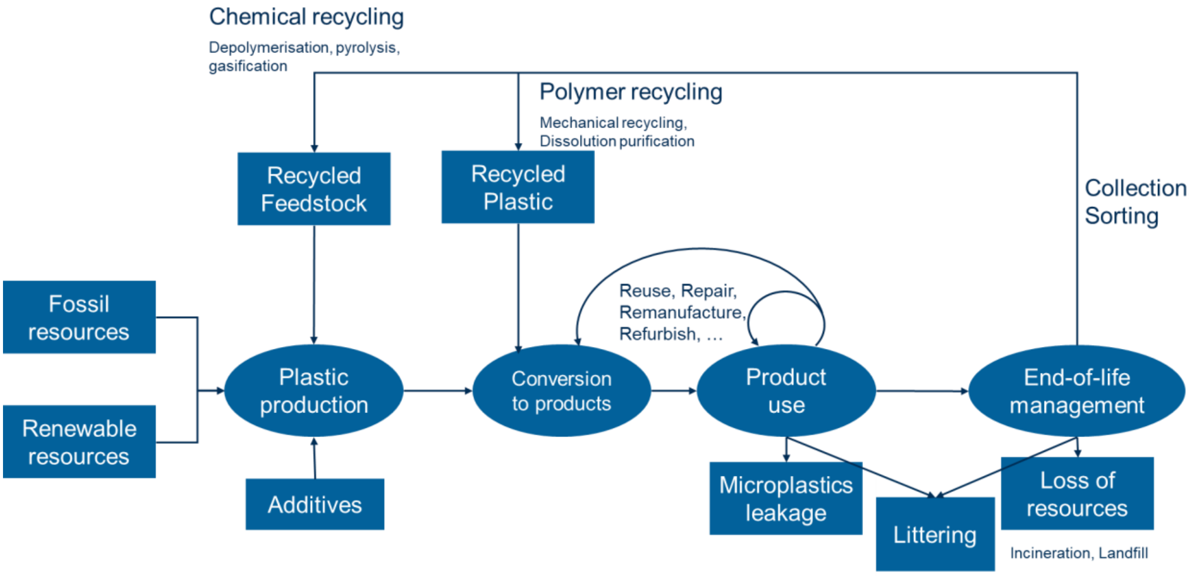


Figure 2. The EU plastics value chain

Several parts of this plastic value chain contribute significantly to biodiversity loss. Well-known hotspots are for instance microplastics and plastic littering, but also the extraction of (both the fossil and renewable) resources to produce plastics impacts biodiversity and ecosystems.
Therefore, the focus areas that will be further explored and elaborated are:

- Extraction of fossil resources (oil, natural gas);
- Extraction of renewable resources (for the production of biobased plastics);
- Microplastics leakage in use phase (cases textiles and automotive);
- Littering (both during use phase and end-of-life phase).

These focus areas are being further briefly described in the remainder of this report, highlighting how they impact biodiversity. This is done based on the direct drivers of biodiversity loss described by IPBES (starting with those with most impact): changes in land and sea use, direct exploitation of natural resources, climate change, pollution and invasion of alien species. (IPBES, 2019) These drivers of biodiversity loss unequivocally influence biodiversity and ecosystem processes by direct physical (mechanical, chemical, noise, light etc.) and psychological (disturbance, etc.) impacts on nature. (Günther et al., 2023; IPBES, 2019)

2.1 Extraction of fossil resources (oil, natural gas)

Description

The first step in the value chain of plastics and plastic products is the extraction of oil and natural gas (Figure 3) when the plastics are made of fossil fuels. Methods to extract oil and natural gas combine various technologies and techniques to maximize the extraction of oil and natural gas from different geological formations and environments, such as:

- Conventional Drilling: vertical drilling into reservoirs where oil and natural gas are trapped, allowing them to flow naturally or with the help of pumps.
- Horizontal Drilling: drilling wells vertically and then turning horizontally to access a larger area of the reservoir, often used in conjunction with hydraulic fracturing.
- Hydraulic Fracturing (Fracking): injecting high-pressure fluid into rock formations to create fractures, allowing oil and natural gas to flow more freely into the wellbore.
- Offshore Drilling: extracting oil and natural gas from beneath the ocean floor using rigs and platforms, which can include both shallow water and deepwater drilling.
- Enhanced Oil Recovery (EOR): techniques such as injecting water, steam, or chemicals into reservoirs to increase the amount of oil that can be extracted.
- Oil Sands Extraction: mining and processing bitumen-rich sands, typically using surface mining or in-situ techniques like steam-assisted gravity drainage.
- Tight Oil and Shale Gas Extraction: a combination of horizontal drilling and hydraulic fracturing to extract oil and gas from low-permeability shale formations.

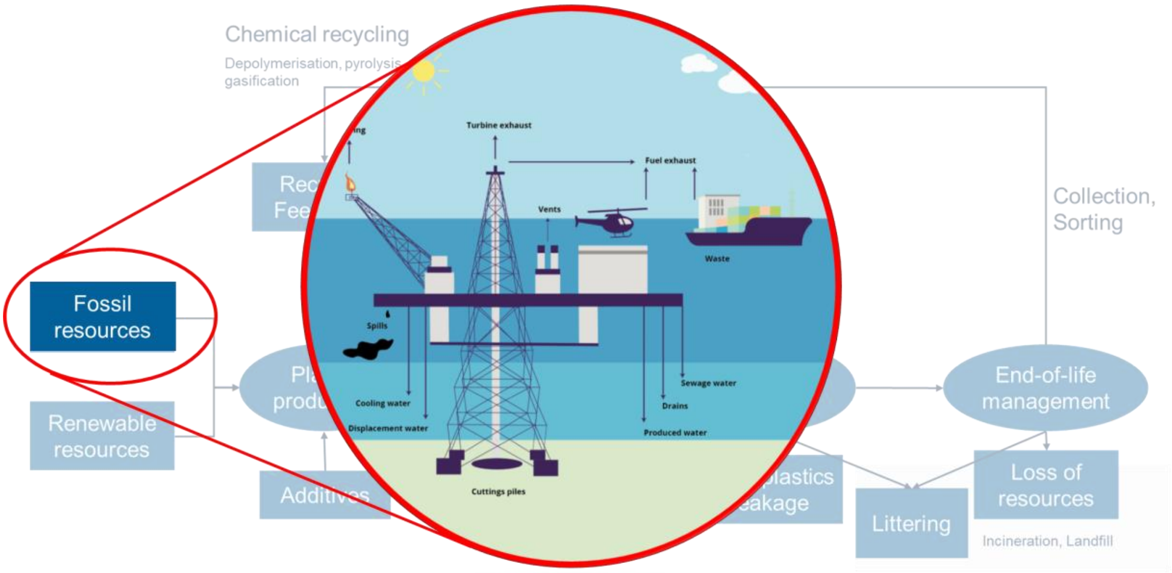
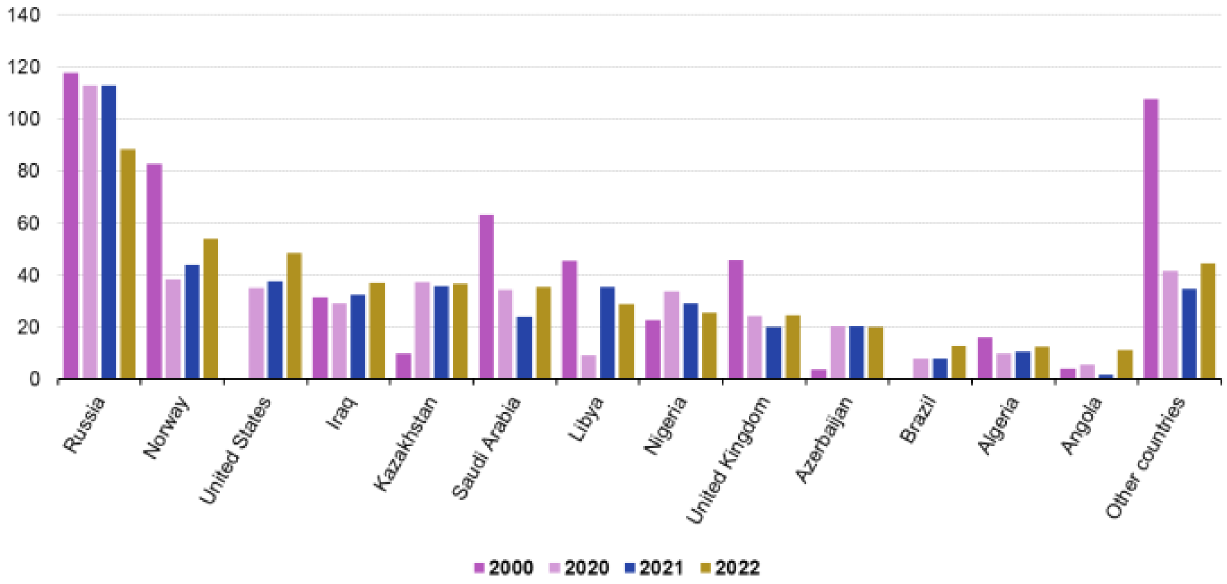


Figure 3. Illustration of oil and natural gas extraction

While the extraction of crude oil in the EU (mainly in Denmark, Italy and Romania) keeps decreasing, the oil imports dependency of the EU surged a new record high to 97,7 %.

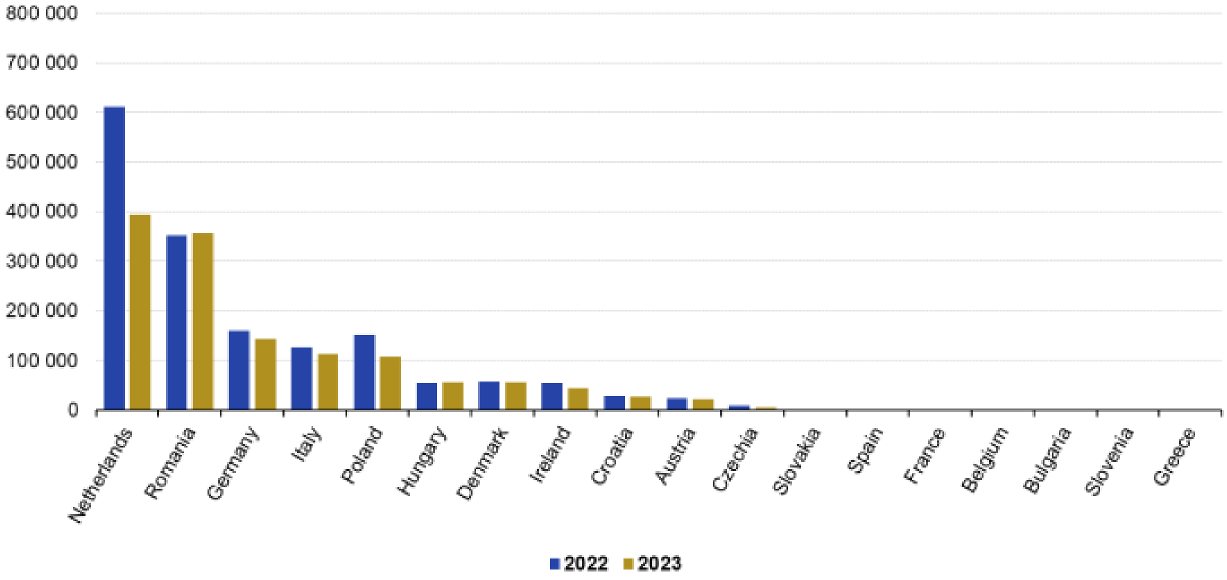
Until 2022, Russia was the largest supplier to the EU, but imports from Russia decreased by almost 22 % in 2022 due to sanctions. This decrease was compensated by increased imports from Saudi Arabia, the United States and Norway. Other suppliers include Iraq, Kazakhstan, and Nigeria, each accounting for a significant share of total EU imports.



Source: Eurostat (online data code nrg_ti_oil)

Figure 4. EU crude oil imports by country of origin, 2000-2022 (in million tonnes), *Source*: Eurostat (nrg_ti_oil)

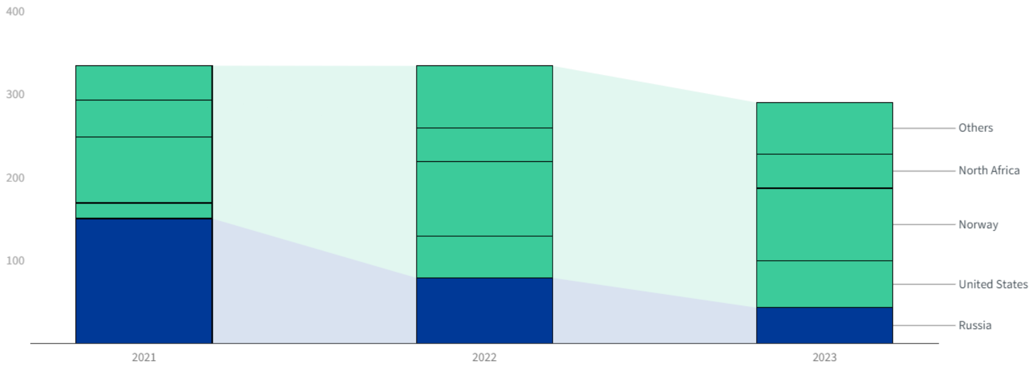
EU natural gas production continued its decreasing trend, falling by 18.6 % in 2023 compared with 2022. The main EU natural gas producer, the Netherlands, registered a drop in production of 35.5 %. The Netherlands remains the highest producer of natural gas in the EU, followed by Romania and Germany (Figure 5).



Source: Eurostat (online data code: nrg_cb_gasm)

Figure 5. Primary production of natural gas 2022-2023 (in terajoules, Gross Calorific Value) *Source:* Eurostat (nrg_cb_gasm)

For EU imports of natural gas, the share of Russia's pipeline gas dropped from over 40% in 2021 to about 8% in 2023 (Figure 6). For pipeline gas and liquid natural gas (LNG) combined, Russia accounted for less than 15% of total EU gas imports.
The drop was possible mainly thanks to a sharp increase in LNG import and an overall reduction of gas consumption in the EU.



Source: European Commission based on ENTSO-G and Refinitiv

Figure 6. Import of pipeline gas in EU, 2023 (in billion cubic metres (bcm))
Source: European Commission based on ENTSO-G and Refinitiv[1]

Biodiversity impacts

Fossil fuel extraction activities, including coal mining, oil extraction, and gas infrastructure, have been found to overlap with areas of higher biodiversity compared to locations without extraction infrastructure. (Harfoot et al., 2018) Evidence has also shown that two-thirds of offshore hydrocarbon activities globally occur within the top 10% areas for species richness and range rarity (Venegas-Li et al., 2019). Existing fossil fuel extraction infrastructure is thereby often located in areas with high biodiversity, both on land and in the ocean. This research points out that the spatial aspect of fossil fuel resources is highly relevant to consider with regards to biodiversity impact, and that extraction activities are to a high degree already overlapping with important areas for biodiversity.

Habitat loss and degradation

Oil and gas extraction contribute to a number of different impacts on biodiversity. Land-use and sea-use transformation play a large role in these impacts (Butt et al., 2013). This transformation comes from construction and use of infrastructure at the extraction sites, and from construction and use of surrounding infrastructure, including roads and pipelines. Transformation of the landscape and seascape leads to habitat loss through destruction and fragmentation, affecting biodiversity negatively.

Pollution

Extraction of fossil fuels is known to contaminate air, water and soil, with a number of different substances that affect the surrounding ecosystems. Pollution stems from everyday operations as well as from accidents and unforeseen circumstances.

Fossil fuel extraction activities also bring risks of spills and leakages in the local environment, which pollutes water, air and soil. Oil spills are well known nature catastrophes which have detrimental effects

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[1] https://www.consilium.europa.eu/en/infographics/eu-gas-supply/#0

for the local biodiversity, not least in the marine environment (Butt et al., 2013). The impact of each spill is dependent of the extent and amount of oil spilled, and the type of habitat it is spilled in.

Another relevant type of pollution comes from visual and noise disturbance from extraction infrastructure. These disturbances come from sources such as drilling rigs, flare stacks, fracking and mining operations, vehicle traffic, and landscape conversion (Dorman and Kartha, 2022). Increased noise levels from these types of sources are known to impact biodiversity negatively, especially species that rely on acoustic communication. For example, both chronic oil well noise and acute oil drilling noise have been found to affect habitat use of birds, impacting their nesting success and nesting quality (Rosa and Koper, 2022). Light pollution from the same type of sources is another issue, although there is little research as environmental responses are difficult to detect empirically (Jones et al., 2015).

Invasive species

Exploration, construction, and use of fossil fuel extraction areas increase the risk for introduction of invasive species. Pathways such as transport vehicles for fossil fuels, soils brought for development, and nature restoration using non-native plants may all contribute to introduction of invasive species (Jones et al., 2015). Moreover, disturbed habitats, especially soils, which exist at extraction areas are more sensitive to introduction of invasive species and can increase the risk for settlement and disturbance of these organisms. Invasive species can reduce biodiversity, and threaten the population of native species (Dorman and Kartha, 2022).

Climate change

Extraction of fossil fuels are indubitably at the start of the value chain of all fossil fuel use, and therefore a main contribution to climate change, which is one of the major drivers of biodiversity loss globally. In addition to this, the extraction activities are in themselves large consumers of fossil fuels, and also subject to leakages of fossil gas, leading to direct global warming impacts which affect biodiversity. Moreover, land use impacts climate change. The physical infrastructure of extraction activities replaces natural soil and vegetation surfaces with impermeable surfaces, reducing the potential for carbon sequestration in these areas.

2.2 Extraction of renewable resources (for production of biobased plastics)

Description

Globally, bio-based plastics currently account for less than 1% of total plastic production with a total production volume of over 2 million tonnes per year. (ETC CE, 2024c) This market is experiencing significant growth and is expected to grow faster than in previous years, with projections indicating to double the share of total production capacity of bio-based, biodegradable, and compostable plastics by 2025. (EC, 2022) In the EU, about 390 000 tonnes of biodegradable materials were produced in 2022. (European Bioplastics, 2023)

Figure 7. Illustration of renewable resources for production of biobased plastics

Bio-based plastics are used as alternatives to conventional fossil-based plastics, which helps alleviate the dependency of fossil fuels. They can be categorized by feedstock (biological materials), and then divided into biodegradable and non-biodegradable. (ETC WMGE, 2021a)

With regard to the feedstock, three distinctions can be made ((European Commission et al., 2022):

1. Cellulosic and carbohydrates-containing feedstock like sugar cane, corn, wheat or starch potatoes, but also non-food biomass like wood and waste streams from agriculture and forestry (straw, bagasse, bark);
2. Oleaginous feedstock like palm oil, soy or sunflower plus waste streams like tall oil and used vegetable oils and fats;
3. Moreover, post-consumer and post-industrial organic waste is considered as feedstock for biobased plastics.

At present more than 50 % of biobased plastics is produced from sugar (25 %) and starch (38 %) originating from highly productive crops like sugar cane and corn. Non-food biomass like wood is used for roughly 14 % of the production and castor oil for circa 19 %; another 3 % is based on vegetable oil (European Commission et al., 2022, p. 9).

The EU emphasizes the need for these plastics to be produced sustainably, ensuring they do not harm biodiversity or ecosystems. The use of organic waste and by-products as feedstock is prioritized to minimize environmental impacts. While bio-based plastics can reduce dependency on fossil resources, they must be designed for circularity, allowing for reuse, recycling, and safe biodegradation. (EC, 2022)

There are several ways of refining and processing biomass. Typically, the raw material is refined into precursors, such as acids, glycerol or glucose, for the monomer production phase. These monomers are then polymerised and finally converted into plastic products. The main three approaches are:

1) the use of natural polymers, such as in starch-based plastics;
2) the polymerisation of bio-based monomers and oligomers through fermentation or conventional chemical processes, for example, for the production of polylactic acid;
3) the polymerisation through bacterial fermentation, used, for example, in the production of polyhydroxy alkanoates.

Biodiversity impacts

Land use change, habitat loss and degradation

Biodiversity loss is closely tied to land conversion for agriculture and forestry, with bio-based plastic production potentially driving both direct and indirect land-use changes (ETC WMGE, 2021a). According to global estimates, the current cultivation of plants for bioplastic production only takes up 0.03 % of the global agricultural area (European Bioplastics, 2024) and use less than 0.04% of the worldwide biomass demand (European Commission et al., 2022), but if all fossil-based plastics production were to be converted into bioplastics production, the required biomass volume would be about 5 % of the total amount of biomass produced and harvested each year (EEA, 2018). If all EU plastic packaging would be substituted by bio-based plastics, of 6 % of the global corn production would be required (Brizga et al., 2020). In addition, it needs to be noted that the production of raw materials for bio-based plastics require the use of land in competition with food production.

The crops use for bioplastic are generally produced in monocultures on large-scale farms. This type of agricultural practice can have substantial impacts on the ecosystems. Increased use of pesticides, herbicides and fertilisers, increased landscape homogeneity, drainage of waterlogged fields, loss of patches of marginal and uncropped habitat and reduced fallow periods are the main causes and accelerators of biodiversity loss (Lewandowski, 2018). Crop production using inappropriate cultivation methods leads directly and indirectly to soil degradation through erosion and compaction and are also factors that affect the loss of biodiversity (Lewandowski, 2018; Islam et al., 2024). In addition, deforestation and land use changes are strongly linked to biodiversity loss, e.g. the conversion of tropical rainforests into sugar cane plantations. But also indirect land-use change matters, e.g when land that was originally used to grow food for human consumption is converted to grow a crop, such as starch potatoes, used for bio-based plastics and the food is imported from elsewhere, possibly from where forests have been converted to agricultural land to support the new demand (ETC WMGE, 2021a). It has to be stated that the risk for indirect land-use change is expected to be smaller for wheat, sugar cane, maize, and sugar beet, than for oil crops (CE Delft, 2017).

Water usage for irrigation in bio-based plastic production is another critical concern, as agriculture accounts for 70% of global freshwater withdrawals. This has led to water depletion and scarcity, particularly in regions like Asia, Africa, and North America (ETC WMGE, 2021a). Deforestation also disrupts water regulation and purification.

Climate change

Although bio-based plastics can offer benefits through sustainable sourcing, the greenhouse gas emissions of their value chain depend significantly on the type of raw materials used. Assessing the effects of land use in lifecycle analyses remains complex, but it is clear that both direct and indirect land-use changes can impact overall emissions (ETC WMGE, 2021a).

Pollution

With bio-based plastics, the feedstock production phase causes pollution and depletion mainly through fertilization and use of pesticides (ETC WMGE, 2021a). Their use can lead to an increase in eutrophication and acidification and therefore for increase of pollution in soils and water bodies (Tsiropoulos et al., 2015; Zuiderveen et al., 2023; Islam et al., 2024)

2.3 Microplastics

Microplastic leakage can either relate to intentionally added microplastics (primary microplastics) to products to achieve intended properties (e.g. microbeads in personal care, ...) or through leakage of unintentionally produced microplastics (secondary microplastics) during production (e.g. pellets) or usage (e.g. paints, washing of textiles, tyre abrasion, …) (see Table 1). Finally, also the degradation and fragmentation of larger microplastic pieces abandoned, discarded or improperly disposed of in the environment will contribute to leakage of microplastics.

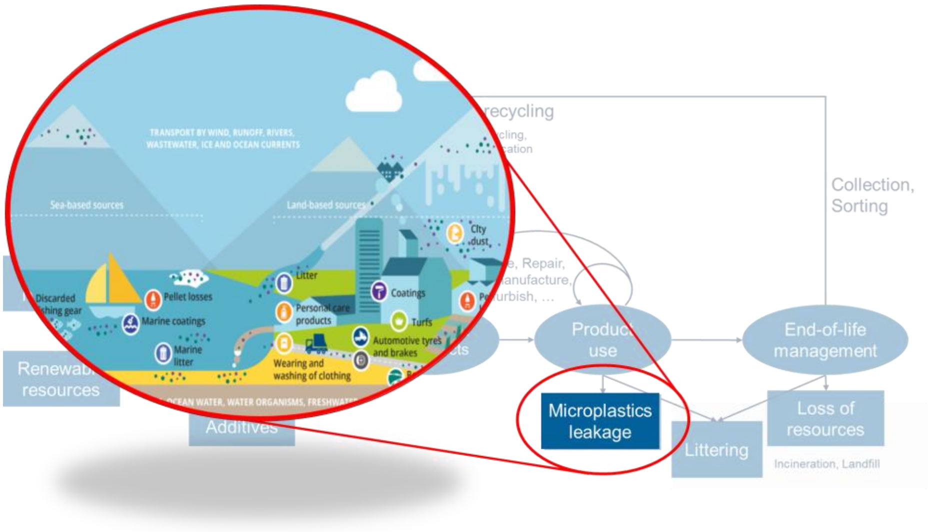

Figure 8. Illustration of microplastics leakage

Regardless their origin, microplastics lead to physical pollution, and, depending on the additives in the plastics, can also lead to chemical pollution (see Box *Additives in plastics*, p. 19).

Source	**Quantity (tonnes/year), 2019**
Paints	231 000 – 863 000
Tyres	360 000 – 540 000
Pellets	52 140 – 184 290
Textiles	1 649 – 61 078
Geotextiles	6 000 – 19 750
Detergent capsules	4 140 – 5 980
TOTAL of the selected six sources	654 929 – 1 674 098 (90-93% of total emissions)
TOTAL of all sources	729 087 – 1 808 198

Table 1: Total primary microplastics emissions, estimated yearly emissions (in per cent)
Source: (European Commission, 2023)

Within the scope of this report, we focus on two case studies on primary microplastic leakage during use, being textiles and automotive tyres, as illustrations how they lead to biodiversity loss
Similar analyses could be made for other relevant sources of microplastics such as paints, pellets, geotextiles, …

2.3.1 Textiles

Description

Microplastics from textiles are typically fibre-shaped polyester, polyamide (nylon), but also acrylic (polyacrylonitrile), elastane (Lycra) or cotton (non-plastic) based. It is estimated that between 1 649 and 61 078 tonnes of primary microplastics from textiles to the EU environment each year. (European Commission, 2023) The microfibres are released during mostly during the washing, drying and wearing steps. (De Falco et al., 2019; UNEP, 2018; ETC WMGE, 2021b; EEA, 2021). These microplastics' release to the environment occurs mainly to the air (during wearing and drying) and water (during washing) where they end up as integrated particles in the natural ecosystems. Wastewater treatment technologies in Europe capture around 90% of the microplastics generated during washing, but 10% still ends up in the waterways. In addition to this, some of the sewage sludge captured through wastewater treatment is used as fertiliser on agricultural fields, creating a pathway for microplastics to the terrestrial environment (de Souza Machado et al., 2018b).

Biodiversity impacts

Pollution

Microplastics from textiles are known to pollute terrestrial, freshwater and marine environments. In marine environments, the same currents that supply nutrients and oxygen to the deep-sea bottom and thereby support biodiversity, are known to be main transport paths for microplastics, suggesting that there is an overlap between deep-sea biodiversity hotspots and microplastic hotspots (Kane et al., 2020).

Synthetic fibres have been pointed out as microplastics with especially high potential to be consumed by organisms and enter the food chain because of their size and shape, which makes them highly consumable for many organisms. This means that they are at high risk of entering the food web and being bioaccumulated. Moreover, fibre-shaped microplastics tend to have higher risk for blockage of the digestive tract in organisms, which can lead to starvation and negative effects on growth and reproduction (Henry et al., 2018).

Another point of concern for biodiversity are the chemical impacts from plastic microfibres. These are, at this point, poorly understood in an environmental context, as there is high complexity in ecosystem impacts stemming from chemical leaching and cocktail effects. Nevertheless, it is known that chemicals have impacts both directly, through leaching of harmful chemicals from plastics, and indirectly, through adsorption of chemicals onto the hydrophobic surface of microplastics. Adsorption of harmful chemicals may have negative impacts when microplastics are ingested by organisms, where the chemicals may be released in the digestive system or transferred further in the food chain (de Oliveira et al., 2023). These risks of chemical impacts are potentially higher for fibre-shaped microplastics, such as the ones from textiles, as they have a larger surface area, and thereby higher potential for chemical sorption, as well as higher retention time in the gut which can lead to more chemical leaking in the organisms (Henry et al., 2018). Chemicals stem from the synthesis of textile fibres and the construction of textile products, where they have been applied as pigments, antimicrobial agents, wrinkle-resistance, and retardants for water, stains, and fire (Athey et al., 2022). This includes chemical groups such as PFOS and PFAS, phthalates and other types of persistent, bio-accumulative, and toxic substances, which may impact organisms and ecosystem health.

Invasive species

Microplastics may work as vectors for spreading of microorganisms. The surface may carry microbes that can spread to new habitats and cause diseases or affect the ecosystem balance (de Souza Machado et al., 2018b; Henry et al., 2018)

Habitat loss and degradation

Microplastics present in soil may affect soil fauna by affecting their soil function. For example, earthworms have been found to make their burrows differently when microplastics are present in the soil (de Souza Machado et al., 2018b). As earthworms act like an ecosystem engineer, influencing the biophysical structure, nutrient cycling, and plant growth, this may have effects on habitats at the ecosystem level.

2.3.2 Tyres

Description

Tyres (and road) wear particles (TRWP) are estimated to be one of the main sources for microplastics in the EU environment and to cause between 360 000 – 540 000 tonnes of microplastics emitted to the EU environment each year. (European Commission, 2023) These rubber microplastic particles contain harmful substances such as polyaromatic hydrocarbons (PAHs) and benzothiazoles that are used during the manufacturing process. Release of TRWP to the environment is considered one of the more difficult sources to control and limit.

Release of these microplastics are directly related to areas with high traffic (i.e. urban areas, highways,..) but run-off into sewage, implying accumulation of TRWP in urbanized and coastal ecosystems. The direct impact of these particles on the environment is not fully understood and there is a need for further investigation to estimate toxicological impact in the environment in order to fill knowledge gaps on the presence and fate of the TRWP, and the impact on biodiversity of these microplastics. (Baensch-Baltruschat et al., 2021) (Mattsson et al., 2023) (Halle et al., 2020a)

Biodiversity impacts

There are few studies on biological effects of particles from tyres and road wear, but many more effect studies on microplastic derived from materials generally regarded as plastics. Microplastics from tyres consist of rubber, plastic materials, or a mix of the two, making them different in their composition compared to other plastics, which means that they may lead to different effects than other types of plastics. (Halle et al., 2020b) (Earth Action, 2023)

Evidence from few laboratory studies carried out on aquatic organisms shows that toxic substances are leached from tyre thread particles, however the concentration varies significantly between studies. The studies were carried out on small crustaceans and, in some cases, on fish, tadpoles, and algae. The toxic effect was in most cases found to be induced by zinc and organic compounds. Chronic toxicity tests lead to effects such as delayed development, reduction of growth and number of offspring, deformity, and death. Moreover, ingestion studies of tyre particles have shown that organisms ingest the particles, and that they excrete them with their fæces (Andersson-Sköld et al., 2020).

Breakdown of tire particles, for example caused by photoaging, may have significant effect on the tire particles and their properties, however there are many knowledge gaps related to these processes (Mayer et al., 2024). Deterioration processes can affect the specific surface area and release of associated pollutants to the environment which can be transferred into food chains.

In order to increase the evidence base on the effects of tyre microplastics on biodiversity, there is a need for studies that consider:

- Environmentally relevant concentrations of tyre rubber and tyre string particles.
- Effects on other types of organisms than the types studied so far.
- Effects on ecosystem level by examining multi-species systems.
- Effects of environmental weathering processes on the physical and chemical properties of tyre particles.

2.4 Leakage to the environment

Description

Leakage of plastics to the environment during the use phase involves the improper or uncontrolled disposal of plastic (containing) items. Based on data from the OECD approximately 22 million tonnes of plastics, are released to the environment every year worldwide (OECD, 2022). Sources of release can be both land- and sea-based, whereas mismanaged waste is the largest source of plastic leakage (OECD, 2022). Other sources include agriculture, fisheries and aquaculture, building and construction, transportation and shipping, offshore operations, ship-based tourism, plastic transport, littering and illegal dumping of waste (UNEP, 2023).

Littering can contribute to the presence of both primary and secondary microplastics in the environment Improper disposal of products containing primary microplastics can lead to their direct release into the environment, while littered plastics can also breakdown into secondary microplastics over time due to exposure to sunlight, wind and waves.

The presence of additives in these plastics can lead to chemical pollution (see Box *Additives in plastics*, p.19).

Quantifying the exact amount of plastic littered during the use phase in Europe is challenging due to the variability in data collection methods and reporting across different countries, but several studies and reports provide estimates and insights into the scale of plastic littering in Europe.

A considerable amount of about 3 million ton plastic waste is not collected or managed properly in Europe. (ETC ICM, 2022) At the same time, the major cause (80 %) of marine litter is poor waste management and littering on land, and approximately 85 % of it is plastic (mainly (50%) single-use plastic items) (UNEP, 2021).

The Waste Framework Directive enforces strict measures against the improper disposal of waste and obliges EU Member States to pinpoint and tackle the primary sources of litter, particularly in natural and marine areas. It establishes stringent recycling and reuse objectives for municipal waste, including plastics, and necessitates the segregated collection of plastic waste. Also, the Single Use Plastics Directive (SUPD) aims to reduce the impact of certain plastic products on the environment, including leakage to the environment.

Biodiversity impacts

Plastic litter is a serious threat to the environment and biota due to the persistence of plastics in the environment (de Souza Machado et al., 2018a). Aquatic ecosystems are often the final destination of plastic littering (Eriksen et al., 2014; OECD, 2022) using different routes from land e.g. by rivers or wind as well as by commercial activities on sea like lost fishing nets et cetera with broad impacts on marine and avian biodiversity (Wurm et al., 2020). Over 200.000 tonnes of plastic waste enters the Mediterranean Sea every year, a number that is expected to double if significant measures are not taken (IUCN, 2020).

Globally, the total accumulated stock of plastics in aquatic environments in 2020 is estimated to 152 million tons (OECD, 2024) and conservative estimates assume that already 14 million tonnes of microplastics covers the ocean floor (Barrett et al., 2020). But, terrestrial microplastic pollution has been estimated to be four to twenty-three times higher than marine microplastic pollution and this could have long-lasting effects on the ecosystem (de Souza Machado et al., 2018b). According to FAO & UNEP (2021) improper use of agricultural plastics leading to littering represent in a significant source of soil pollution with substantial impacts on land-based ecosystems and biodiversity. In the EU, 720 000 tonnes of agricultural plastics are used on an annual basis (European Bioplastics, 2023) only about 63% of agri-plastic (non-packaging) waste was collected (2019), with the remaining 37% likely stored, burnt, buried, or mixed with other waste (2019). Despite their high recycling potential, only 24% of agri-plastic materials on the EU market are recycled annually. (EC, 2022) Collected films may end up in landfills instead of recycling as some recycling facilities reject contaminated plastic films (de Sadeleer and Woodhouse, 2024). Conventional films left in fields or lost in nature can accumulate, or if mulch films are not fully removed, which cannot always be ensured, they release plastics that accumulate in soils, fragment into microplastics, or spread by wind or runoff, and they disrupt gas exchange and water infiltration (de Sadeleer and Woodhouse, 2024) (EC, 2022) It is estimated by European bioplastics (2021), that 950 000 hectares of agricultural soil are polluted by plastic residues. The transition towards certified soil-degradable mulch is witnessed in the EU, e.g., in Italy and Spain using 2 kt/a and 1.5 kt/a of certified soil-biodegradable mulch respectively. (European Bioplastics, 2023)

Littering leading to animal death

Plastic waste can be directly or indirectly lethal to animals in different ways including ingestion leading to starvation and laceration in internal systems, entanglement, smothering of coral reefs or due to toxic substances (UNEP, 2021; OECD, 2022). According to the EU Technical Group Marine Litter, 817 marine species are regularly affected by harmful effects of litter in the seas and oceans. Of these, 519 are affected by choking or strangulation and swallowing pieces of litter. Above all, packaging materials and ring or cord-shaped pieces of litter as well as remains of nets, lines and ropes harbour a high potential of danger for marine life. Around 17% of these species are on the red list or are already classified as threatened or endangered (JRC, 2016). Also terrestrial biodiversity is impacted by plastic wastes through plastic ingestion and entanglements of land animals when mistaken for food or used as nesting materials or shelter (Anunobi, 2022).

Entanglement – Entanglement is one of the major effects of littering of so-called macro-plastics. For example, 55% of bird orders and 21% of bird families are affected by entanglement (Ryan, 2018). Entanglement in plastic litter like ropes, nets and monofilament lines from lost or discarded fishing gear wrap themselves around animals causing strangulation, wounds and restricted movement increasing vulnerability to environmental hazards and predators (Anunobi, 2022; Ryan, 2018; Tekman et al., 2022). For birds a special kind of entanglement exist. Birds incorporate plastic litter items to their nests, including ropes, bags or foils, is often reported (Horton and Blissett, 2021; Ryan, 2018). Using this material can entrap parents and hatchlings possible leading to starvation when the parents are no longer able to forage for food or the nestlings' beaks are knotted together (Anunobi, 2022; Horton and Blissett, 2021).

Ingestion – Plastic ingestion is widely reported and is common for small fragments and items of debris, such as bottle caps, balloons and sewage-related debris. Animals ingest plastics directly when they mistake it for food or prey due to its shape, colour or smell or indirectly along the food chain by eating prey that has ingested plastic (Anunobi, 2022; Horton and Blissett, 2021). Plastic ingestion has been documented in 1,288 marine species and 277 freshwater and terrestrial species across all trophic levels (UNEP, 2023). In marine ecosystems all species of marine turtles, almost 60 % of whale species, 36 % of seal species and 40 % of seabird species are impacted by plastic ingestion (Kuhn et al., 2015). Ingestion of plastic wastes by land mammals including elephants and cattle, resulting in death of these animals are also reported (Horton and Blissett, 2021). Plastic ingestion can lead to internal injuries or block the digestive tract affecting food uptake by creating a false sense of satiation, which could lead to reduction in stomach volume and starvation of the animal (Derraik, 2002; Tekman et al., 2022; Ferreira-Filipe et al., 2021). Further, it can have negative impacts on growth, immune response, fertility and reproduction (Tekman et al., 2022). The ingestion of plastic can also have negative effects on soil organisms and thus on soil quality as microplastic ingestion could cause intestinal blockage and tissue damage in nematodes and earthworms (Anunobi, 2022).

Diseases - Plastic pollution, especially microplastics, has become an environmental health risk as it can act as vectors of pathogenic organisms (UNEP, 2021; Anunobi, 2022).

Due to their hydrophobic surface and longer half-life than most natural substrates, plastics in the environment is colonized by a diverse microbial community constituting the “Plastisphere”. Such plastics and plastisphere can, therefore, promote the distribution of potential pathogens to other environments (Ferreira-Filipe et al., 2021).

Pollution

The pollution effect of plastic litter is manifold. In general, plastics, and due to the hydrophobic properties and extensive surface area especially microplastics (see also chapter 1.3), may act as a sink and transportation media for chemicals and persistent organic pollutants (POPs), which accumulate on the surface of plastics e.g. while in seawater (OECD, 2022; Islam et al., 2024; JRC, 2016). Plastic fragmentation may enhance leaching of chemical substances to the surrounding environment (UNEP, 2021; OECD, 2022; UNEP, 2023). Plastic additives (see Box *Additives in plastics*, p. 19) are known to exhibit a wide range of toxicities to various organisms in different ecosystems. They can move into the surrounding environment through a process of diffusion, which is influenced by various factors like the porosity and thickness of the polymer, hydrophobicity of the additives, the characteristics of surrounding matrices or weathering (Maddela et al., 2023; Kumar et al., 2021). Additives may cause changes in gene and protein expression, inflammation, disruption of feeding behaviour, decreases in growth, behave like mutagen and carcinogen, and display detrimental impacts on animal reproductive cycle (UNEP, 2021; Kumar et al., 2021; Maddela et al., 2023).

Degradation of plastics from macro- to micro- and further into nano-particles in the environment is of recent concern due to their reported ecotoxicity and the possibility of their entering living organisms in the food chain (Dissanayake et al., 2022; ETC WMGE, 2021a; JRC, 2016). It is known as the plastic particle size decreases, the possible chemical-like effects increase, which is why nano-plastic-particles are of particular concern because their small size allows them to potentially be transferred to tissues or cells (OECD, 2022; ETC WMGE, 2021a). When microplastics move into the soil it can act as a pollutant as it can be accumulated into the bodies and tissues of soil organisms limiting their activities and growth or decrease entire populations e.g. of nematode worms and microarthropods (Anunobi, 2022). In addition, microplastic can affect soil properties such as moisture, density, structure, and nutrient content, which may impact plant growth and nutrient uptake (Dissanayake et al., 2022).

Habitat loss

The impairment or loss of habitat in the sea is mainly due to the fact that the deposition of microplastics causes corals, sponges and bottom animals to lose light, food and oxygen, negatively impacting corals and their symbiotic algae, causing them to die and altering reef community structures. In addition, the sea bottom and reefs become depleted of oxygen up to so called death zones (JRC, 2016; Tekman et al., 2022; Kane et al., 2020).

Invasive species

Plastics constitute one of the vectors for diverse invasive species, ranging from macro fauna to toxic microorganisms, as they drift on litter across great distances in marine ecosystems (JRC, 2016; Anunobi, 2022; Ferreira-Filipe et al., 2021; de Souza Machado et al., 2018b). A total of 387 taxa, including microorganisms, seaweeds and invertebrates, have been found rafting on floating litter in the oceans (JRC, 2016).

BOX: Additives (including chemicals) in plastics

Plastics are made from both polymers and additives. Additives are chemicals and substances added during manufacturing to create wanted properties or to fulfil specific functional requirements for processing and/or final plastic material or product, e.g., flexibility, improve processability, UV resistance, flame retardancy, … Typical added additives are plasticizers, flame retardants, pigments, antioxidants, stabilizers, antistatics and nucleating agents.

Additives are mostly produced following a similar petrochemical production process as monomers starting from crude oil or natural gas but are typically processed further from platform chemicals. Some of these platform chemicals can also be used as monomers such as ethylene and propylene.

Many of the additives are not chemically bound to the polymer matrix, which makes it easier for them to be released from the plastic. Despite the benefit additives bring for the functionality of plastic products, their potential to contaminate soil, air, water and food is well documented in literature. (Hahladakis et al., 2018)

The review by (Aurisano et al., 2021) concluded a list of more than 6000 chemicals reported to be found in plastics. They further analysed over 1500 plastic-related chemicals of concern (Wiesinger et al., 2021). indicated over 10 500 different additives being used with plastics, of which over 2400 substances were identified as substances of potential concern. Potential concern was evaluated if the substance was identified one or more criteria from persistence, bioaccumulation, and toxicity.

The estimated global production of plastic additives in 2019 was 20 million tonnes. If production of plastics is to be continued as estimated, the additive production is estimated to rise to 2000 million tonnes by 2050. The global plastic additive market is expected to grow by 5.7% from 2021 to 2028.

The most common additive used in plastics are plasticizers that provide flexibility, durability and stretchability. Plasticizers are most often used in PVC in applications such as automotive, flooring, roofing, pipes and cables. Plasticizers are also used in acrylics, PET and polyolefins. Phthalic esters used with PVC make up about 80 % of the plasticizers used with PVC (Hahladakis et al., 2018).

Flame retardants can be halogen-based, e.g., brominated flame retardants, but also phosphorous compounds and aluminium hydroxide are most commonly used. Most thermoplastics require the addition of flame retardants to be able to withstand higher temperatures. Flame retardants are therefore seen especially in electrical and electronic equipment, construction, and automotive applications (Hahladakis et al., 2018).

With respect to impact on the environment and human health, it is not only the production of additives that is relevant, but particularly the exposure during (unintended) release of plastics such as in microplastics and littering.

3. Pathways to circular plastics as mitigation of biodiversity loss

A circular economy can play a crucial role in mitigating biodiversity loss in several ways. (ETC CE, 2023) First, by reducing primary resource demand, it increases efficiency in resource use, extends product lifespans, and promotes recycling. This lowers the demand for primary resources, thereby reducing pressure on biodiversity. Second, preventing pollution involves stopping waste leaking into the environment and reducing hazardous substances, which protects natural environments and human health. Third, biodiversity-friendly sourcing focuses on obtaining resources in ways that avoid harming natural systems and promote regenerative practices.

The three main pathways towards sustainable and circular plastics are smarter use, increased circularity and renewable materials. (EEA, 2023) These three pathways focus on different actions throughout the EU plastics value chain as illustrated in Figure 9.

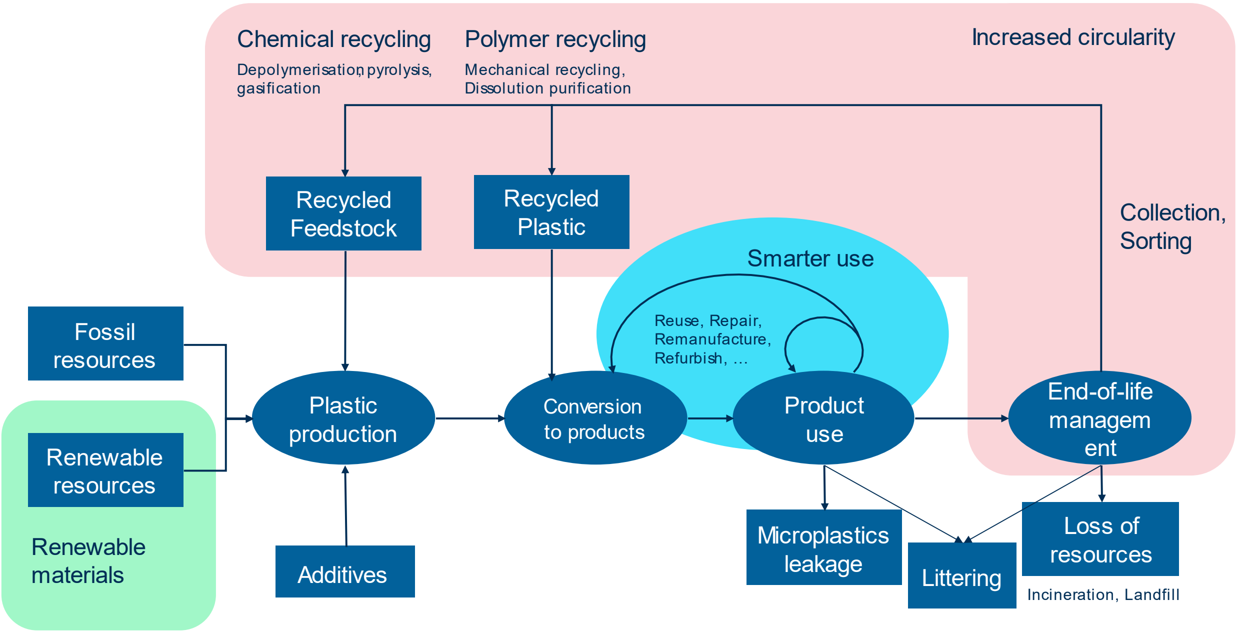

Figure 9. Pathways to circular plastics and the EU plastics value chain

In the next paragraphs, per pathway is described how it can mitigate biodiversity loss, specifically for the analysed hot spots.

1. Smarter use

The smarter use pathway focuses on rethinking when and why plastics are used and aims to reduce the use of unnecessary plastics, redesign plastic-containing products and extend the lifetime of plastic products already in use through reuse, repair and other strategies. This pathway is located in the blue area in Figure 9.

The smarter use pathway focuses on decreasing the need for raw materials and mitigate the impact of the extraction of (fossil and renewable) resources on biodiversity loss at the source. If fewer materials are required, fewer biodiversity loss related to material extraction will occur.

The roll-out and scaling of access-based circular business models that are part of this pathway enable consumers to access goods and services that meet their needs without requiring them to own the product itself. Since in this business model, the product is owned by a central service provider that is incentivised to maximise the products use, the context for littering is undermined. This could result in decreased littering and, resultantly, a potential mitigation of biodiversity loss through littering.

The leakage of microplastics from textiles and tyres is mostly related to the product composition and is inherently coupled to the product design. A focus on rethinking the product design in such a way that the release of microplastics is decreased or avoided, could mitigate the biodiversity loss associated to microplastics leakage. This is not related to circularity of plastics, but is rather a complementary measure.

2. Increased circularity

The increased circularity pathway focuses on closing the materials loop through higher resource efficiency and lower material (and value) losses, with a strong focus on (high quality) plastic recycling. Actions on this pathway include the increased collection and improved sorting of plastics as well as connecting recycling and recycled materials markets and are typically located in the pink area in Figure 9.

The strong focus on high-quality recycling of this pathway aims to provide the market with large volumes of recycled plastics that can directly replace virgin plastics in applications. As a result, a larger fraction of the plastic demand will be met with recycled plastics, and a lower amount of virgin (fossil or renewable) resources will be needed. This pathway therefore mitigates the biodiversity impact of fossil and renewable resource extraction.

Furthermore, focusing on increased plastic recycling also includes further development and improvement of end-of-life management systems and waste collection and sorting systems that prevent plastic littering (e.g. Extended Producer Responsibility (EPR) schemes), hereby mitigating the biodiversity impacts of littering.

The increased circularity pathway is less directly related to the avoidance of microplastics, as the creation and release of microplastics are not typically associated with the waste treatment processes (especially for microplastics produced during the use phase as considered in the scope of this report), although decreased littering will also result in a lower creation of microplastics from littered plastics.

3. Renewable materials

The renewable materials pathway focuses on promoting renewable feedstock-based solutions to support the decoupling from fossil-based feedstocks. The pathway focuses on the beginning of the value chain, located in the green area in Figure 9.

Where fossil fuel extraction mainly impacts biodiversity as pollution, climate change and habitat loss, renewable feedstock extraction is merely related to land use, deforestation, competition with food resources, and water and fertiliser use. So, there is no clear winner, but rather a trade-off when it comes to biodiversity impacts of resource extraction for plastic production.

Since biobased plastic is not always biodegradable and biodegradability is defined under specific conditions, the renewable materials pathway does not necessarily imply a mitigation of biodiversity impacts of microplastics. Plastics produced from renewable materials are still prone to form polluting microplastics using identical mechanisms that are present for their fossil counterparts (e.g. abrasion of tyres, washing textiles, paints, …)

A false idea of biodegradability might create an increased littering behaviour by consumers that associate biodegradability with full disintegration to water and CO_2 in nature.

In this pathway, mitigation of biodiversity impacts on littering and microplastics therefore must still include clear communications on the properties and performance of renewable plastics to make sure that this renewable feedstock is kept in the circular economy loop for as long as possible.

4. Conclusions

The current way of managing plastics and plastic products has a negative impact on the environment and on biodiversity, which is not always accounted for. This negative impact is not limited to pollution during end-of-life (waste) phase, but occurs throughout the entire plastics value chain including resource extraction, production and use, where harmful substances linked to plastics can leak into the environment.

The analysis of four hotspots of biodiversity impacts of plastics illustrates how all steps in the plastic value chain contribute to biodiversity loss in different ways. The extraction of fossil resources (oil, natural gas) and renewable resources for biobased plastics significantly affect biodiversity through habitat loss, pollution, and the introduction of invasive species. Microplastics leakage during the use phase, such as from textiles and tyres, but also from paints and pellets, are a major concern as they pollute terrestrial, freshwater, and marine environments. Plastic littering, especially in marine environments, has severe consequences, including ingestion and entanglement, which can lead to injury or death. Marine ecosystems are often the final destination for plastic leakage, exacerbating the problem.

While resource extraction for plastic production has a more direct and immediate impact on biodiversity through habitat destruction and pollution (of air, land, water), plastic leakage to the environment has long-term and pervasive effects on ecosystems. Both are critical issues that need to be addressed to protect global biodiversity.

Improving circularity of plastics, both emphasizing smarter use, increased circularity and renewable materials offer important tools to help to mitigate some of these biodiversity impacts. However, significant challenges will persist in each step of the plastics value chain related to biodiversity loss. Additional measures, substantiated by integrated approaches tackling the interconnectedness of biodiversity, climate change and pollution, are needed to be able to find a way to protect our environment and biodiversity from detrimental effects of plastics and plastic products management. Future analyses and measures should be multifaceted, addressing all relevant issues in an integrated way, as actions to mitigate climate change, reduce pollution, and protect biodiversity are interconnected.

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