UNITED
NATIONS

UNEP/PP/INC.4/INF/1

United Nations
Environment
Programme

UNEP

Distr.: General
16 April 2024

English only

Intergovernmental negotiating committee to develop an international legally binding instrument on plastic pollution, including in the marine environment
Fourth session
Ottawa, 23–29 April 2023
Item 4 of the provisional agenda*

Preparation of an international legally binding instrument on plastic pollution, including in the marine environment

Plastic pollution science (updated for the fourth session of the intergovernmental negotiating committee)

Note by the secretariat

1. Pursuant to paragraph 5 of the United Nations Environment Assembly resolution 5/14 of 2 March 2022, titled "End plastic pollution: towards an international legally binding instrument", an ad hoc open-ended working group met in Dakar from 30 May to 1 June 2022 to prepare for the work of the intergovernmental negotiating committee to develop an international legally binding instrument on plastic pollution, including in the marine environment. The open-ended working group agreed on a list of documents that the secretariat would provide to the intergovernmental negotiating committee at its first session. Among other things, the secretariat was requested to provide a document on plastics science, including monitoring, sources of plastic pollution, chemicals used in manufacturing, flows across the life cycle, pathways in the environment, health and other impacts, solutions, technologies and costs.

2. Accordingly, document UNEP/PP/INC.1/7 was prepared and published ahead of the first session of the intergovernmental negotiating committee.

3. The secretariat has prepared an update of UNEP/PP/INC.1/7 for the fourth session of the intergovernmental negotiating committee. The update provided in the annex to this present note, contains the latest available information on plastic pollution science. Approximately 70 new or updated references have been added. The updated document expands on key terminology relating to plastic pollution, and incorporates new data and findings published in peer-reviewed scientific journals and reports published by intergovernmental organizations. Definitions of key terms used throughout this document are for reference only and do not supersede any outcomes of the intergovernmental negotiating committee.

4. The document is not meant to be a comprehensive overview of all potential solutions and technologies and their costs and benefits.

5. The document has not been formally edited.

* UNEP/PP/INC.4/1.

Annex

Plastic pollution science (updated for the fourth session of the intergovernmental negotiating committee)

Contents

A. Summary

1. **The world has seen a massive increase in plastic production.** Global plastic production and consumption has grown exponentially since the 1950s and is set to increase by 70 per cent by 2040 if business continues as usual.[1] Plastic production is associated with the use of chemical additives and other substances, many of which are of concern for human and environmental health, including a subset listed as hazardous under the Stockholm Convention and in national legislation.[2]

2. **There is increasing clarity regarding the links between plastic and human and environmental health.**[3,4,5] The links between plastic with its associated chemicals and plastic pollution with its detrimental effects on human health and the environment are increasingly clear, although plastic's contribution to the global burden of disease across its life cycle has not yet been comprehensively quantified.

3. **Plastic pollution is lethal for many species.** Plastic pollution in all forms causes lethal and sublethal effects in a wide array of organisms in marine, freshwater and terrestrial environments.[4,6] Plastics can also alter global carbon cycling through their effect on plankton and primary production in marine, freshwater and terrestrial systems. A one per cent decline in annual marine ecosystem services could equate to an annual loss of $500 billion in global ecosystem benefits.[6]

4. **Throughout its life cycle, plastic also contributes to climate change**.[7] In 2020, plastics generated 3.6 per cent of global greenhouse gas emissions – 1.8 billion tonnes CO2 equivalent – with 90 per cent of quantifiable emissions coming from plastics production and conversion from fossil fuels, and the remaining 10 per cent of quantifiable emissions released during waste management and treatment.[1,8]

5. **The resource-inefficient, take-make-waste plastic economy is at the core of the plastic pollution crisis**.[9,10,11,16] Solving plastics pollution and its unintended and multiple consequences requires shifting incentives towards sustainable consumption and production levels, with safe, efficient and circular uses of plastic in the economy and acknowledging that some uses cannot be made circular and may need to be eliminated from the economy unless they are essential.

6. **Millions of workers in informal settings ensure some level of waste collection and recycling in many countries across the world**.[12] Measures taken to address plastic waste pollution must be inclusive of informal waste pickers, and the transition towards a circular economy for plastics must be leveraged to improve working conditions.[13]

7. **Circularity in the economy is a critical part of the solution.**[14,16] Science shows that by shifting the plastics economy to a comprehensive circular economy approach across the life cycle, most plastic pollution could be prevented.[1,9] Benefits (compared to a business-as-usual scenario in 2040 if comprehensive and coordinated approaches are not applied) include a 25-41 per cent reduction in greenhouse gas emissions across the global plastic life cycle.[1,15] Modelling studies suggest that a comprehensive circular economy approach will also save governments $70 billion over the period 2021–2040 and create 700,000 additional jobs, mainly in the global South.[15,16]

8. **A comprehensive and integrated approach to solutions is needed.**[1,4,14,16] A number of successful legislative and policy options are demonstrated in this document. Importantly, scientific evidence, outlines the need for a comprehensive and integrated application of solutions across the life cycle of plastics. Solutions may include a combination of regulatory, voluntary, economic, technological and behavioral instruments, as well as the use of trade policies.

9. **Following a life-cycle approach is critical.** As was highlighted in UNEP/PP/INC.1/11, the best combination of policies across the life cycle will differ based on each Member State's needs. But following a life-cycle approach and applying policies in an integrated way can set the world on the path to a more circular plastics economy.

10. **Harmonized measures and legal obligations will be key**. To support national actions, a harmonized set of measures and legal obligations agreed internationally will be key to creating a level playing field. For example, agreed measures on product design would reduce the challenges of managing plastic waste, which often occurs in a region other than where the products were designed. Section G presents options for measures across the life cycle, which, if applied in an integrated way, would help achieve the necessary change to end plastic pollution.

11. **Ending plastics pollution is possible, but this demands vision, targets, monitoring and reporting.** Scientific literature shows that a shift towards a more safe and circular plastics economy is possible with the knowledge we have today.[9,17] This requires a new, shared global vision where plastic pollution is not an option, coupled with the set of targets, policy instruments and mechanisms that will

lead and enable the shift towards this vision. Strong monitoring of harmonized indicators and reporting will enable accountability and transparency.

B. Key concepts and terminology

1. Plastics, plastics polymers and plastic additives

12. **Multiple definitions of plastics are used across sectors and organizations**. For example, in the 2023 Basel Convention technical guidelines on the environmentally sound management of plastic wastes[i], plastic is described as "a synthetic material or modified natural material, either a polymer or combination of polymers of high molecular mass modified or compounded with additives such as fillers, plasticizers, stabilizers, flame retardants and colorants".[18] The International Organization for Standardization (ISO) defines plastic as "a material which contains as an essential ingredient a high polymer and which, at some stage in its processing into finished products, can be shaped by flow".[19]

13. **Similarly, there are several definitions of polymers**. The Basel Convention technical guidelines of the environmentally sound management of plastic waste describe polymers as "natural or synthetic substances composed of very large molecules, called macromolecules, that are multiples of simpler chemical units called monomers".[i,18]

14. **Polymers can be classified into several classes, but are commonly classified into two: thermosets and thermoplastics**.[18] Thermoset plastics are polymers that after being set into a mold cannot be re-softened or molded again. Common thermosets are urea formaldehyde (UF) resins, phenol formaldehyde (PF) resins, and melamine formaldehyde (MF) resins. Thermosets are most commonly used for high-heat applications such as electronic equipment, appliances, construction and insulation. Thermoplastics, on the other hand, can be reshaped and recycled under specific conditions, and include polyethylene, polypropylene and polystyrene. Thermoplastics are commonly used for most domestically consumed plastics.

15. **Additives are substances added to plastics to alter specific characteristics of the plastic.**[18] There are several classes of additives, including, but not limited to plasticizers, flame retardants, stabilizers (including antioxidants and UV stabilizers), biocides, fillers and colorants.[18]

2. Nano-, micro- and macroplastics

16. **Nano-, micro- and macroplastics are terms commonly used to describe plastics and plastic fragments of specific dimensions.** The definitions and boundaries of these terms vary[20].

17. **Again, numerous definitions exist for microplastics though they are commonly defined by their particle size.** For example, the ISO defines microplastics as "Any solid plastic particle insoluble in water with any dimension between 1 µm and 1000 µm (=1 mm)"[21], whereas the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) uses a more expansive definition of "Particles in the size range 1 nm to <5 mm".[22]

18. **Nanoplastics are commonly considered to be particles and fibers smaller than the lower size boundary of microplastics,** typically < 1 µm (=1000 nm). Some definitions do not have a lower size boundary at 1 nm[21,23]. Similarly, macroplastics are understood to be plastic items, particles and fibers larger than the upper boundary of microplastics (>5 mm).[23]

19. **Microplastics can be further differentiated according to the source or types of particles**. Key categories in use are primary and secondary microplastics. Primary microplastics are typically plastics that are intentionally designed to be small in size for their application and use[20]. Primary microplastics may include e.g. intentionally added microplastics (microbeads, industrial abrasives, polymer encapsulated agricultural products) and plastic pellets, flakes and powders. Secondary microplastics are microplastics generated from use or degradation of plastics and plastic products, and may include tire, brake and road wear particles, paint fragments, microfibers and particles released from the degradation and weathering of plastic wastes.[20]

3. Non-plastic substitutes and alternative plastics

20. **Non-plastic substitutes** describe the use of alternative materials or approaches in applications where plastics are currently utilized.[24] Sustainable substitutes should have lower adverse impacts

[i] The Basel Convention guideline has been negotiated and established through consensus-building processes under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal.

across their life cycle.[24] This may include use of paper, cardboard, metal, glass or other materials derived from mineral, plant, animal, marine or forestry origin.

21. **Alternative plastics is a term used to describe plastics and plastic products derived from alternative sources to conventional petrochemicals**, this encompasses bio-based and biodegradable plastics from a variety of sources such as starches, cellulose, chitosan, polylactic acid (PLA) and polyhydroxyalkanoates (PHAs).[25]

22. **Bio-based plastics are made from biomass instead of fossil fuels**. Despite being made from different feedstocks, some bio-based plastics may be chemically indistinguishable to fossil-based plastics (e.g., bio-based polyethylene), while others are alternative plastics (e.g., PHAs).[26] In some cases, the term bio-based plastics is used to describe materials that are at least partially developed from biomass containing organic carbon from renewable sources.[27]

23. **Some fossil-based and bio-based plastics may be designed to be biodegradable or non-biodegradable under specific conditions.** [26] At present, there is limited regulation of the use of the term biodegradable, though it is commonly understood to refer to plastics that degrade under specific conditions. For biodegradation to take place, specific conditions in terms of temperature, UV radiation, humidity, oxygen content and pH, as well as the presence of specific microorganisms, are required for the plastic material to fully degrade into carbon dioxide, water, biomass and inorganic compounds. The conditions required depend on the chemical and physical structure and composition of the plastic material.[28] If these conditions are not met, the biodegradable plastic material will not fully degrade. This is especially a concern as some plastic products labelled as biodegradable have been shown to persist in the environment.[29]

24. **Compostable plastics are a sub-category of biodegradable plastics.** Compostable plastics can fully degrade under controlled conditions in industrial composting facilities. However, similar to other biodegradable plastics, compostable plastics may not biodegrade in the environment or home composting systems. Additionally, not all industrial composting facilities have the conditions required to treat compostable plastic waste. This means that industrial composting facilities and separate collection systems are required to utilize the benefits of compostable plastics. Home-compostable plastics are also being developed, but a recent experiment found that 61 per cent of the plastics tested and labelled as home-compostable did not fully degrade.[30]

4. The plastic life cycle and life-cycle approaches

25. A **life-cycle approach to plastics** considers the impacts of all the activities and outcomes associated with the production and consumption of plastic materials, products and services – from raw material extraction and processing to design, manufacturing, packaging, distribution, use (and reuse), maintenance and end of life management, including segregation, collection, sorting, recycling and disposal.[31] Transportation and trade of plastic products also occur at each stage of the life cycle. Plastic leakage can happen at any stage, although the end of life and use stages are where the biggest share originates.[32]

26. **Consideration of the full life cycle allows the hidden costs and trade-offs of different environmental, social and economic impacts and different stages of the life cycle to be taken into account**, ensuring that one solution to a particular problem does not create a greater negative impact elsewhere.[33,34] A life-cycle approach also helps to identify the stages that have the highest impact (hotspots) and evaluate alternatives for reducing their impact. For instance, studies by the UNEP-hosted Life-cycle Initiative on single-use plastic products and their alternatives[35] show that, in most cases, reusable products outperform single-use plastic products across all environmental impact categories.[ii]

5. Plastic pollution

27. **There is not yet a universally accepted definition of plastic pollution.** In UNEP/PP/INC.1/7 the following working definition was provided for the purposes of the initial version of this document: "Plastic pollution is defined broadly as the negative effects and emissions resulting from the production and consumption of plastic materials and products across their entire life cycle. This definition includes plastic waste that is mismanaged (e.g., open-burned and dumped in uncontrolled

[ii] All the studies from the Life-cycle Initiative on single-use plastic products can be found at: https://www.lifecycleinitiative.org/single-use-plastic-products-studies/. More information on life-cycle approaches can be found on the Life-cycle Initiative webpages.

dumpsites) and leakage and accumulation of plastic objects and particles that can adversely affect humans and the living and non-living environment".

C. Trends in plastic production, waste generation and chemical use in manufacturing

1. Production

28. **Plastic production is set to increase by 70 per cent by 2040.** Annual global production of plastics doubled from 234 million metric tons in 2000 to 460 million metric tons in 2019. It is forecast to grow by 70 per cent under a business-as-usual scenario to exceed 700 million metric tons in 2040.[1] Global plastic materials production in 2020 was dominated by the following regions: Asia (49 per cent), North America (19 per cent) and Europe (15 per cent).[36]

29. **The speed of projected growth of plastic use differs across regions.** Between 2020 and 2040,[iii] countries that are not members of the Organisation for Economic Co-operation and Development (OECD) are projected to almost double their plastics use. They are expected to account for 63 per cent of global plastics use by 2040, with the largest increases expected in emerging economies in Africa and Asia. Plastic use in OECD member countries is projected to increase by more than a third by 2040.[37] By 2060, OECD member countries are set to remain the largest consumers of plastics on an average per capita basis: 238 kg, compared with 77 kg in OECD non-member countries.[38]

30. **The speed of projected growth of plastic use also differs across sectors.** In 2020, packaging, construction and vehicles accounted for 60 per cent of total plastic use. While plastic use is expected to grow across all applications by 2040, the greatest percentage growth is expected for transport, electric and electrical products and packaging in a business-as-usual scenario.[37]

2. Composition and products

31. **Table 1 provides an overview of plastics use in 2019, by polymer type (or application)**. Plastics are mainly used in packaging, followed by sectors such as building and construction, transportation and textiles.

Table 1
Plastics use in 2019 by polymer (or application)

Polymer	*Millions of metric tons*	*Percentage*
Other	81	18
Marine coatings	0.5	0
Low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE)	54	12
High-density polyethylene (HDPE)	56	12
Polypropylene (PP)	73	16
Polystyrene (PS)	21	5
Polyvinyl chloride (PVC)	51	11
Polyethylene terephthalate (PET)	25	5
Polyurethane (PUR)	18	4
Fibers	60	13
Road marking coatings (application)	1	0
Elastomers (tires)	8	2
Bioplastics	2	1
Acrylonitrile butadiene styrene (ABS); acrylonitrile styrene acrylate (ASA); styrene Acrylonitrile resin (SAN)	9	2
Total	**460**	

[iii] In a business-as-usual scenario.

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

32. **Up to 99 per cent of plastics are made from polymers derived from non-renewable hydrocarbons**, mostly oil and natural gas.[39] Additives – such as plasticizers, fillers, stabilizers, colorants and flame retardants – help to maintain, enhance and impart specific characteristics (e.g., flexibility, fire resistance) and colors to the plastic.

33. **Some 86 per cent of the global market is dominated by thermoplastics**.[39] Thermoplastics include polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS) and polyphthalamide (PPA). Polyethylene, the most popular thermoplastic, includes low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE) and high-density polyethylene (HDPE).

34. **Plastic products with an average lifespan lower than 5 years made up approximately two thirds of plastics use in 2019.**[iv] Short-lived plastic products include packaging made from LDPE (e.g., bags, containers, food packaging film), containers made from HDPE (e.g., bottles, shampoo bottles, ice cream tubs) and PET (e.g., bottles for fluids).[39]

35. **Durable or long-lasting plastic products found in buildings and construction, transportation, electronics and machinery made up around one third of plastic product use in 2019.**[38] Such items may be in use from around 8 years (in electronics, for example) to more than 20 years (in construction materials and industrial machinery).[40]

36. **Material use varies across sectors.** PET, PP and LDPE are most commonly used for packaging, whereas construction accounts for the majority of PVC used. Consumer products, electronics and vehicles meanwhile utilize a much broader range of polymers and polymer blends.[38]

3. Chemical use

37. **Around a quarter of the over 16,000 unique plastic chemicals are of potential concern to human health and safety**.[2] These chemicals are either added deliberately during the production process[v] or are unintentionally added by-products, breakdown products or contaminants.[vi]

38. **Some plastic related chemicals are regulated under the Basel, Rotterdam, Stockholm, Montreal and Minamata Conventions.**[2, 41] A recent review found that 980 plastic chemicals, or 6 per cent of identified plastic chemicals, are regulated under existing multilateral environmental agreements (either as an individual chemical or identified in a group or classification of chemicals).[2]

39. **Ten groups of specific chemicals associated with plastics have been identified as being of major concern.** These include specific flame retardants, certain UV stabilizers, per- and polyfluoroalkyl substances (PFASs), phthalates, bisphenols, alkylphenols and alkylphenol ethoxylates, biocides, certain metals and metalloids, polycyclic aromatic hydrocarbons, and many other non-intentionally added substances (NIAS).[42] These are identified due to their high toxicity or potential to migrate or be released from plastics. A separate study identified fifteen groups of chemicals of concern based on their persistence, bioaccumulation, mobility or toxicity, encompassing more than 4200 chemicals of concern.[2]

40. **Chemicals of concern can be released throughout the plastic life cycle…** including during the extraction of raw materials, the production of polymers, manufacture of plastic products, as well as at the end of life, including during recycling, disposal in landfills and, especially if not properly managed, contributing to releasees to air, water and soils.[42]

41. **… and from a wide range of sectors.** Chemicals of concern have been found in plastic toys and other children's products, packaging (including food contact materials), electrical and electronic

[iv] These include packaging (40 per cent), consumer products (12 per cent) and textiles (11 per cent). See OECD, *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options* (Paris, OECD Publishing, 2022).

[v] Including additives such as fillers, flame retardants, plasticizers, antioxidants, antimicrobial agents, ultraviolet stabilizers, pigments and catalysts trapped in plastic resins.

[vi] There may be a variety of chemical compounds present in plastic materials that are not added for a technical reason during the production process and that can originate from various sources. Such non-intentionally added substances include breakdown products of food contact materials, impurities of starting materials, unwanted side-products and various contaminants from recycling processes. See Birgit Geueke, "Dossier – Non-intentionally added substances (NIAS)" (June 2018).

equipment, vehicles, synthetic textiles and related materials, furniture, building materials, medical devices, personal care and household products, and agriculture, aquaculture and fisheries.[42]

4. Plastic waste and recycling

42. **Plastic waste[vii] is forecast to rise, with the packaging sector being the largest generator.** A rise from an estimated 360 million metric tons per year of plastic waste in 2019 to 1,014 million metric tons per year in 2060 is expected under a business-as-usual scenario.[38] Plastic waste in Asia and Africa is forecast to quadruple by 2060.[38] The packaging sector is the largest generator of plastic waste (46 per cent), followed by the textile (15 per cent), consumer products (12 per cent), transportation (6 per cent), building and construction (4 per cent) and electrical and electronice (4 per cent) sectors. Forty per cent of all plastic packaging waste ended up in engineered landfills, 32 per cent was lost into the environment, 14 per cent was incinerated (with or without energy recovery) and 10 per cent was recycled (8 per cent into lower value applications and 2 per cent into similar applications); an additional 4 per cent was sent to recycling but was lost in the process.[39]

43. **In practice, at-scale recycling[viii] in specific countries/regions is limited.** An expert survey of members of the New Plastics Economy Global Commitment network[43] indicated that, while many polymers may be recyclable in theory, only a handful of packaging formats have been demonstrated to be recycled in practice and at scale in specific countries and regions. Those products are PET bottles, HDPE bottles and other HDPE rigid formats (e.g., pots, trays, cups), PP bottles, and PE mono-material flexibles bigger than A4 in size, the latter only in the business-to-business context (e.g., pallet wraps) and EPS for transport packaging (e.g. fish boxes or protection of large items).

44. **Most other packaging formats and polymers have not been shown to be recycled in practice** and at scale (e.g., PET trays and other thermoforms; PP other than bottles; business-to-consumer formats of PS and expanded/extruded polystyrene (EPS/XPS); all flexible formats except PE in business-to-business contexts), even if they might technically be recyclable.[43] While the survey sample is relatively small, it provides a first step towards better data availability and transparency on plastic recycling, and indicates the most problematic packaging formats.

45. **More plastic waste is mismanaged than collected for recycling, with global projections for recycling remaining low.** Global recycling rates are forecast to remain low over the coming decades, increasing from less than 9 per cent in 2020 (34 million metric tons), to 14 per cent in 2040 (84 million metric tons).[37] Global recycled (secondary) plastics use is projected to stay at a relative standstill at 6 per cent of total plastics use in 2040 in a business-as-usual scenario.[1]

D. Plastic pollution sources and pathways in the environment

46. **Mismanagement of waste is by far the biggest contributor to plastic pollution.[40]** By type of plastic product application, short-lived plastic products – dominated by plastic packaging and other single-use plastic products – represent the biggest source of plastic pollution.[15] While fishing gear and agricultural plastics represent a smaller volume, their direct use and impacts in the environment is problematic.[44]

1. Plastic pollution sources

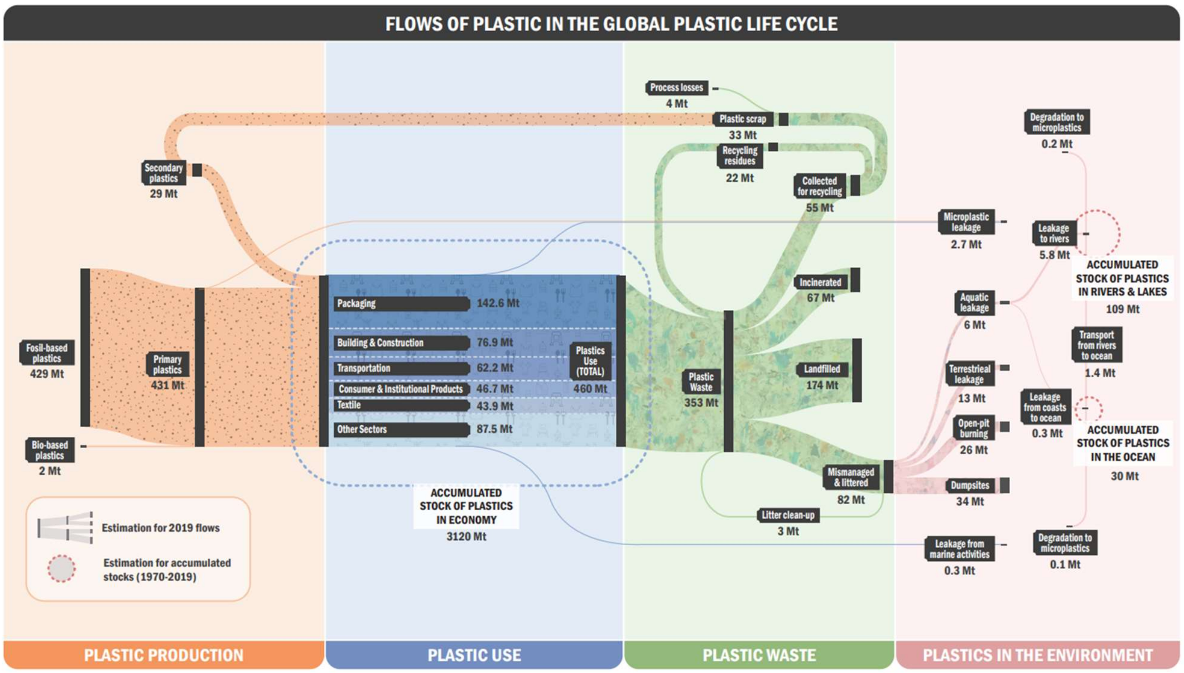
47. **An estimated 82 million metric tons of mismanaged plastic waste were produced in 2020, with a 40 per cent increase projected by 2040**.[37] Figure 1 depicts the major flows of plastic in the economy, showing the main sectors using plastics (estimated for 2019); the main sources of plastic leakage into the environment (in 2019) and stocks in the economy and the environment (1970–2019).[38] The size of these flows and the projections are highly uncertain according to the OECD, due to lack of robust information on key data points such as the share of mismanaged waste lost to the environment.[1,38]

[vii] Five different waste-handling categories (recycling, incineration, landfilling, mismanaged waste and littered waste) are considered in this modelling. Biodegradable plastics that can be composted at the waste stage are not included because this stream remains very small. See OECD, *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options* (Paris, OECD Publishing, 2022).

[viii] The Ellen MacArthur Foundation defines recycling in practice and at scale for plastic packaging as packaging that achieves a 30% post-consumer recycling rate in multiple regions, collectively representing at least 400 million inhabitants, and with a 30% post-consumer recycling rate achieved in the Pact market(s). If the threshold is met either globally or locally then it can be concluded for the purposes of the Plastics Pact reporting that a 'system for recycling' exists for that plastic packaging category.[44.]

48. **Today's plastic economy is largely linear.** In Figure 1, the relative thickness of the flows shows clearly that the current plastics system is mainly linear, from virgin (fossil-based) plastic production to disposal and leakage into the environment, with very small circular flows being cycled back (top flow of secondary plastic). A circular plastics economy would show a thick flow of plastic being cycled back into "plastics use" as "secondary plastics" (top feedback loop) and very small inflows of new "virgin" plastic (not necessarily from fossil fuels) and outflows going into final disposal (with zero plastic leaking into the environment).[45]

Figure 1
Flows of plastic in the global plastic life cycle, and losses to and accumulated stocks in the environment



Note: "Institutional products" refers to products sold mainly to businesses as opposed to individuals (e.g., cleaning products sold to cleaning companies rather than households); "other sectors" includes a wide array of sectors such as electrical equipment, industrial machinery, road markings and marine coatings.

Source: Figure built from OECD, *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options* (Paris, OECD Publishing, 2022).

2. Macro- and microplastics leakage

49. **Macroplastics accounted for 88 per cent** of global plastic leakage to the environment in 2019, around 20 million metric tons. This figure is projected to increase to 30 million metric tons in 2040.[1] Mismanaged plastic waste is the main cause of macroplastic leakage (82 per cent), with littering of end-of-life plastic products second (5 per cent).[38] Macroplastic leakage to the environment is high in emerging economies.[ix]

50. **Fishing gear is particularly problematic, as it often becomes waste on-site in sensitive ecosystems, with high health and environmental risks**, despite its lower production volume. It has been estimated that fishing activities and other marine activities contribute around 0.3 million metric tons[38] to global macroplastic leakage. Global fishing gear losses each year may include 5.7 per cent of all fishing nets, 8.6 per cent of all traps and 29 per cent of all lines.[46] The International Maritime Organization has published a strategy with specific actions to address marine plastic litter from ships.[47]

[ix] Eighty-nine per cent of global macroplastic leakage is in OECD non-member countries, suggesting the need for capacity-building in end-of-life waste management in these countries. OECD, *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options* (Paris, OECD Publishing, 2022).

51. **Agricultural plastics also deserve special attention** for their use close to sensitive ecosystems. An estimated 12.5 million metric tons of plastic products are used annually in plant and animal production.[48]

52. **Synthetic textiles are another source of macroplastic pollution, though the scale of releases remains uncertain.** Synthetic fibers account for at least 65 per cent of global textile production.[49] As synthetic textiles cannot currently be recycled at scale, these materials are either downcycled, incinerated, landfilled or dumped in the environment at the end of use[50].

53. **Secondary microplastics dominate microplastics leakage.** Most microplastics found in the environment are secondary microplastics:[x,39] major sources include road transport (1 million metric tons), the release of dust and fibers (0.81 million metric tons)[38] and wastewater sludge. Microplastics are also released from artificial turf (0.05 million metric tons)[38] during use or after disposal.[39]

54. **Primary microplastics** are also an important source. Pre-production plastic pellets (or nurdles) are an example of primary microplastics (0.28 million metric tons),[38] along with intentionally added microplastics such as microbeads – spherical or amorphous microplastics added to products such as personal care items, fertilizers, paint, detergents, food supplements, hand sanitizers and medicinal products.[39]

55. **Microplastic leakage is projected to increase by 50 per cent** globally, from 2.7 million metric tons in 2020 to 4.1 million metric tons in 2040.[1] Interventions to address microplastics are generally less advanced, as this form of leakage has not received the same level of scrutiny as macroplastics. Microplastic leakage occurs along the life cycle of products.

56. **Municipal wastewater treatment facilities could serve as significant pathways for microplastics leakage into the environment,** with raw sewage containing zero to more than 18,000 particles per liter depending on the source.[51] Microplastics enter wastewater systems through road drainage systems and household and industrial effluents. Upon treatment in wastewater treatment plants, microplastics may be removed and collected in wastewater sludge, and may re-enter the environment through the use of wastewater sludge as fertilizers in agricultural fields, a practice common in several countries.[52] Microplastics that are not filtered out, typically because of lack of adequate filters, will re-enter the environment with the water discharged from the wastewater treatment plants.[51]

3. Plastic pollution environmental pathways

57. **Released plastic travels in the environment.** Once plastics are released into the environment they are transported by various means and processes to even the most remote places. The transport of plastics in aquatic ecosystems is controlled by currents, waves and winds, among other factors.

58. **1,000 rivers deliver 80 per cent of plastic in the oceans.** It has been estimated that more than 1,000 rivers account for 80 per cent of the annual releases of plastic waste to the oceans from global riverine systems (ranging between 0.8 and 2.7 million metric tons per year), with small urban rivers among the most polluting.[53]

59. **The speed of plastics' movement varies...** The rate at which plastic pollution moves along the various transport pathways and the length of time it resides in different environmental compartments depends on its chemical and physical properties, such as buoyancy, surface properties and size, as well as on oceanographic processes and meteorological conditions.[54]

60. **…but move it does.** Microplastics can move through the food web, as well as through the air, soil, ice, snow and water – including groundwater. There is also an indication that sea ice functions as a temporary sink, secondary source and transport medium for microplastics.[55]

61. **Significant knowledge gaps remain.** Knowledge of the absolute volumes of plastics in different habitats remains poor, because of limited sampling coverage and the lack of standardized sampling protocols.[54]

E. Impacts of plastic pollution

62. **The impacts of plastic pollution are increasingly evident** – altering habitats and natural processes, reducing ecosystems' ability to adapt to climate change and directly affecting millions of

---

[x] Numerical estimates of microplastic leakage are limited to quantifiable sources for which there is sufficient data to generate estimates. Even for quantified sources uncertainties exist due to limited information on emissions rates and lack of data points from different environments and conditions.

people's livelihoods, food production capabilities and social well-being. Plastic pollution has a disproportionate impact on the most vulnerable populations.

1. Impacts of plastic pollution on human health

63. **Plastic pollution can pose risks to human health.** At every stage of its life cycle, plastic can pose risks to human health, arising from exposure to the chemicals used in production, the plastic particles themselves and additives.[56] Plastic particles can enter the human body through ingestion and inhalation, while nanoparticles may also enter through the skin.[57] There are concerns that plastics, in particular microplastics, can host microbial pathogens.[58]

64. **Plastic is ingested by humans and wildlife.** Recent studies suggest that adults in the United States of America could be consuming more than 50,000 pieces of plastic a year,[59] with an increased risk of health effects[60]. A study of microplastics in wild-caught fish revealed evidence of plastics in the intestinal tract of 65 per cent of the 496 species examined.[61] New detection methods have revealed that on average a liter of bottled water contains 240,000 micro- and nanoplastics[62], though more research is needed to understand the health and environmental impacts of micro- and nanoplastics.[63]

65. **Consumer exposure to chemical additives may also be significant via major product groups**, including plastic-based food contact materials, building materials, electronics, toys and personal care and household products. A 2021 study[64] found that 25 per cent of children's toys contain harmful chemicals; some 126 substances that could harm children's health were identified, including 31 plasticizers, 18 flame retardants and 8 fragrances.

66. **Occupational exposure to hazardous chemicals is high in the plastics sector.** A review of occupational exposure in Europe listed the plastics, rubber and textile industries as common industrial sectors associated with higher rates of exposure to hazardous chemicals in plastics.[65]

67. **Plastic pollution is also found in the air.** Research is also raising concerns about the contribution of plastic to air pollution and the potential risks to human health through the inhalation of plastics.[66,67] Open burning of plastics results in the release of chemicals of concern, including brominated flame retardants, phthalates, dioxins, furans, polychlorinated biphenyls (PCBs), and potentially toxic elements such as cadmium, lead, chromium and nickel.[12,68] This poses serious risks, in particular to the 11 million informal entrepreneurs who work closely with waste.[12,69,70]

68. **Plastic is found in dust.** Studies indicate that textiles and fibers are major contributors to the plastic materials that enter human lungs, food and the environment.[71] It has been estimated that about 6 kg of the 20 kg of dust generated by the average household annually consist of microplastics.[72] In air, 3 to 7 per cent of particulate matter is estimated to consist of tire wear and tear.[73]

69. **Exposure to endocrine-disrupting chemicals** in plastics and the hazards that such chemicals pose to human health are linked with a range of human diseases and conditions, including cancer, diabetes, reproductive disorders, neurodevelopmental impairment, and immune system suppression.[70,74]

70. **Women and children are particularly vulnerable to chemicals of concern in plastics.** Exposure to plastic associated chemicals can cause neurodevelopmental and/or neurobehavioral related disorders, preterm births, low birth weights, childhood cancers, amongst others.[56] Men are also impacted, and research has documented adverse impacts on male fertility from chemicals associated with plastics.[42,56]

71. **Further research is needed** to establish the relationships between biological exposures to plastics and associated additives, and including microfibers and other plastic microparticles, on humans, and to understand the potential transfer of microplastics and hazardous chemicals to crops and animals.[56,75,76]

2. Impacts of plastic pollution on the environment

72. **The mismanagement of plastic waste has led to contamination of the marine environment, from coastal shores to the deepest ocean sediments**.[39]

73. **When plastics break down in the marine environment**, they transfer microplastics, synthetic and cellulosic microfibers, hazardous chemicals, metals and micropollutants into the water and sediments and eventually into marine food chains.[54,77]

74. **Plastic litter causes lethal and sublethal effects in marine life.** Their effects include entanglement, starvation, drowning, laceration of internal tissue, smothering, deprivation of oxygen and light, physiological stress and toxicological harm.[54,78,79]

75. **Microplastics may act as vectors for pathogenic organisms**. When microplastics are ingested, they can cause changes in gene and protein expression, inflammation, disruption of feeding behavior, decreases in growth, changes in brain development and reduced filtration and respiration rates. They can alter the reproductive success and survival of marine organisms and compromise the ability of keystone species and ecological "engineers" to build reefs or bioturbated sediments.[54]

76. **Tire and road wear particles** can cause negative impacts on certain species due to the release of leachate and from ingestion[80], with tire particles more toxic than leachates alone.[81] Tire wear particles contain a complex blend of chemicals, which may migrate from the polymers at different rates and under different conditions. Recent studies suggest toxicity of tire wear particles may be driven by a few chemicals or groups of chemicals.[82] Of particular concern is the antioxidant 6PPD and its derivative 6PPD-quinone which is highly toxic to certain species.[83]

77. **Plastic pollution can alter global carbon cycling through its effect on plankton and primary production in marine, freshwater and terrestrial systems**. For example, marine microplastics can affect phytoplankton photosynthesis and growth, have toxic effects on and affect the development and reproduction of zooplankton, and affect the marine biological pump and the ocean carbon stock.[84]

78. **Plastic across its life cycle contributes to climate change.** In 2020, plastics generated 3.6 per cent of global greenhouse gas emissions – 1.8 billion tonnes CO2 equivalent.[1] Some 90 per cent of those emissions came from plastic production and conversion from fossil fuels.[1,8] By 2040, greenhouse gas emissions from the plastics life cycle could increase by 60 per cent, reaching 5 per cent of the global carbon budget, incompatible with the Paris Agreement and limiting the ability to achieve the 1.5-degree target.[1,8]

79. **In addition, airborne microplastics may cause positive net radiative forcing**.[85] The light-absorbing properties of microplastics may contribute to accelerated warming by decreasing the surface albedo of snow and ice.[86]

80. **Plastics manufacturing has an impact on the ozone layer and the climate through use of ozone-depleting substances and hydrofluorocarbons as feedstock**. Several ozone-depleting substances and hydrofluorocarbons, which are controlled under the Montreal Protocol, are used as feedstock in the manufacture of plastic products. Feedstock uses of such substances are exempt from phase-out under the Montreal Protocol on the premise that emissions from feedstocks were insignificant; however, leakage does occur, causing adverse effects on the ozone layer and the climate.[87]

81. **The impacts of microplastics on soil ecosystems are increasingly understood, and may be significant.[48]** The accumulation of plastic residues in agricultural soils has been found to adversely affect the physiochemical properties linked to healthy soil and may threaten food production in the long term.[88] Experiments on microplastics and nanoplastics in soils have further been found to negatively impact plant growth, though more research is needed under natural conditions.[89]

82. **The presence of plastic could dramatically shift the ecology of marine and terrestrial ecosystems**. An altered environment and shifts in biodiversity have potentially wide-reaching and unpredictable secondary societal consequences[90] and may impair ecosystem resilience. Plastics can act in concert with other environmental stressors – such as changing ocean temperatures, ocean acidification and the over-exploitation of marine resources – to cause a cumulative larger and more damaging impact.[6]

3. Socioeconomic impacts of plastic pollution

83. **Communities may suffer social impacts differently,** with the impacts of exposure and management of plastic pollution often falling on poorer urban and rural women.[39] Workers in informal and cooperative settings collect, sort and recycle plastics, and are subject to low pay and unsafe working conditions.[91] Addressing plastic pollution will require consideration of the impacts on and opportunities for different communities.[13]

84. **The aggregate value of plastic is lost to the economy when it becomes waste...** Because of the essentially linear nature of the plastics system (take-make-waste), 95 per cent of aggregate plastic packaging value – $80 billion to $120 billion a year – is lost to the economy following a short first use cycle.[92] In addition, it is projected that by 2040 there could be a risk of additional $100 billion in

annual operational and capital expenditures for businesses if governments require them to cover waste management costs at expected volumes and recyclability; plastic waste collection and management is one of the highest cost items for governments (see table 3)[15].

85. **…while plastic waste adds a burden to human health and the environment.** The socioeconomic burden of the health effects associated with endocrine disrupting chemicals is estimated at 46 billion to 288 billion euros per year.[93] While damage to ecosystem services is challenging to calculate, it has been suggested that a 1 per cent decline in marine ecosystem service delivery equates to an annual loss of $500 billion in the value of benefits derived from marine ecosystem services.[6]

86. **Investing in the prevention of waste and pollution at source is less expensive than remediation**.[94] The global economic cost of marine plastic pollution with respect to its impact on tourism, fisheries and aquaculture, together with other costs such as those for clean-up, is estimated to have been $6 billion to $19 billion or more in 2018.[54]

87. **Plastic pollution has a human rights dimension, too**. Finally, plastic pollution can infringe on human rights. Plastic pollution affects people in vulnerable conditions disproportionally – including those living in poverty, indigenous and coastal communities and children – potentially aggravating existing environmental injustices.[54]

88. **Solutions to plastic pollution will have to consider the socioeconomic impacts** of elimination and substitution.[95,96] Measures could consider the impacts, trade-offs and risks of regrettable substitution to avoid adding burdens to vulnerable communities or populations dependent on specific product formats or uses.

F. Monitoring and reporting

89. **Remaining knowledge gaps prevent a full understanding of the global plastic crisis and consequently our ability to confront it in a comprehensive way.** These information gaps have numerous causes, including inconsistent data collection methods, variable or absent metadata standards, and the lack of a centralized data repository. While the lack of detailed evidence should not prevent immediate action, the generation of an evidence base of consistent, high-quality information would support national and global action to tackle plastic pollution.

90. **A harmonized set of metrics could be developed to measure progress toward global and national targets, building on existing data collection activities** (for example, other international agreements and/or the Sustainable Development Goals). Key metrics to monitor could include:

- Sustainable Development Goal indicator 11.6.1: proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities;
- Sustainable Development Goal indicator 12.5.1: national recycling rate, tons of material recycled;
- Sustainable Development Goal indicator 14.1.1b: plastic debris density;
- Total plastic waste generated (this indicator is being reported by government signatories of the New Plastics Economy Global Commitment);
- Total plastic waste recycled (this indicator is being reported by government signatories of the New Plastics Economy Global Commitment);
- Percentage of a population with adequate waste collection;
- Percentage of a population with access to appropriate effective recycling;
- Total plastic production, per polymer type and application (statistics available from industry, not officially reported);
- Total plastic exports and imports, including plastic waste imports and exports;
- Amount of recycled plastic going into new products;
- Plastic waste inventories (the BRS convention has developed a Plastic Waste Inventory Toolkit utilizing a material flow analysis approach);
- Emissions of plastic pollution to the environment.[97]

91. **Some of these metrics may need to be assessed as country baselines in order to then measure progress against them**. Effort is needed to harmonize approaches to setting such baselines at the national level, and to identifying the key flows of plastics and the most effective ways to manage them. One approach could be to calculate relative consumption of plastics and generation of plastic wastes, expressed as production and imports, subtracting exports. There are ongoing efforts to develop new methodologies and harmonization of monitoring approaches, both for monitoring of plastics in the economy, emissions and stocks in the environment.

1. Existing monitoring initiatives

92. Existing initiatives for monitoring plastics in the economy as well as plastic pollution in the environment may be leveraged to build a monitoring framework. Relevant existing initiatives include:

- **Sustainable Development Goal indicator 12.5.1: national recycling rate, tons of material recycled**: The data on municipal waste recycled are national data provided by countries on a biennial basis through the Questionnaire on Environment Statistics, developed jointly by the Statistics Division of the Department of Economic and Social Affairs and the United Nations Environment Programme (UNEP), and the OECD/Eurostat Joint Questionnaire on the State of the Environment. The latest available data are for the period 2000–2021. The next data collection cycle is scheduled for the second half of 2024. Results are published in the Global Sustainable Development Goals Indicators Database and the World Environment Situation Room. In 2021, UNEP launched the "Global Chemicals and Waste Indicator Review Document" to strengthen the knowledge base of chemicals and hazardous waste and enhance the capacity of selected countries to track progress towards related Sustainable Development Goal indicators across sectors. The document provides a coherent methodology for measuring the Sustainable Development Goal indicators related to municipal waste (indicator 11.6.1), hazardous waste (indicator 12.4.2) and recycling rate (indicator 12.5.1).

- **Sustainable Development Goal indicator 14.1.1b: plastic debris density**: In 2021, UNEP launched the methodology for Sustainable Development Goal indicator 14.1.1, entitled "Understanding the State of the Ocean: A Global Manual on Measuring SDG 14.1.1, SDG 14.2.1 and SDG 14.5.1". UNEP and the Regional Seas Programme report the **data** collected from countries for this indicator, including through a harmonized questionnaire for countries that are not members of the regional seas conventions and action plans.

- Another reporting initiative worth mentioning is the **New Plastics Economy Global Commitment**,[98] led by the Ellen MacArthur Foundation and UNEP. More than 500 signatories, including businesses and governments, have committed themselves to taking specific actions across the full life cycle of plastic products and reporting annually on their progress.

- **The Plastics Management Index**, launched by the Economist Impact and the Nippon Foundation, compares and contrasts the efforts made by 25 countries at various stages of development in their management of plastics, covering the entire life cycle of plastic products.[99]

- **The updated technical guidelines for the environmentally sound management of plastic wastes** (UNEP/CHW.16/6/Add.3/Rev) adopted by the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal in 2023 also provide useful guidance for sampling, analysis and monitoring of plastic wastes.

- At the World Trade Organization (WTO), the **Dialogue on Plastic Pollution and Environmentally Sustainable Plastics Trade** (DPP)[100] has been discussing, among other issues, how to better identify trade flows of plastics and plastic goods. In a Ministerial Statement issued at the WTO's 13th Ministerial Conference held in February 2024 (WT/MIN(24)/14), trade ministers agreed to "improve transparency, monitoring and understanding of trade flows throughout the value chain of plastics, including flows of single-use plastics, plastic films and hard-to-recycle plastics." The action would build on previous work by the group, as reflected in the compilation attached to the Statement, including their collaboration with the World Customs Organization (WCO), UNEP, UNCTAD and others.

- Following a call by WTO DPP coordinators, the current **2027 Harmonized Commodity Description and Coding System (HS) reform process** is considering proposals to further breakdown HS codes to facilitate the identification of plastic and plastic-containing goods, as well as single-use, alternative and non-plastic substitute products.

- Under the Stockholm Convention, **the global monitoring plan (GMP) for persistent organic pollutants** was established as a component of effectiveness evaluation.[101] The GMP provides a harmonized framework to identify changes in persistent organic pollutants over time, and information of regional and global environmental transport. The GMP receives data based on sampling in air, human tissues, water and other media across regions.

2. An opportunity to improve data quality

93. **Harmonized metrics can support better assessments and decisions by all actors.** The reporting provisions within the international legally binding instrument on plastic pollution, including in the marine environment, could include requirements for a harmonized set of metrics to enhance transparency and disclosure by public and private sector actors – including the metrics described in this section.

94. **Methods used for data collection could build on and work in coordination with existing reporting schemes**. With enhanced data quality and transparency, stakeholders will be able to inform optimal decisions, companies and investors will understand how their actions and investments contribute to solutions across the plastic value chain, governments will be able to develop the right regulations, policies and targets and consumers and civil society groups will be empowered to hold companies accountable for the plastics produced and sold. Furthermore, the demonstration of credible, continuous progress towards achieving the objectives of the instrument will help to secure political support and financing and ultimately enhance the impact of the instrument over the long term.

G. Solutions and technologies and their costs and benefits

95. **Research on plastic pollution shows the need for a comprehensive, integrated application of solutions across the entire life cycle of plastics[1,40,102].** United Nations Environment Assembly resolution 5/14 shows that this has been embraced politically.

96. **The solutions are based on the pressing need to shift to a resource-efficient circular economy,** where negative impacts throughout the life cycle are minimized, products are kept at their highest value for as long as possible and where plastic is considered a valued resource that continues to circulate in the economy.

97. **The choice and design of policy measures to address plastic pollution will require considerations of socioeconomic impacts**. Ensuring a just transition for industries, including the informal recycling sector, most impacted by measures to end plastic pollution will be necessary for the viability and stability of measures. However, a transition will also provide opportunities for new jobs, business models and sectors to grow, especially within alternative materials, solutions, and technologies. An International Resource Panel report[103] found that up to 700,000 new jobs may be created under a systems change scenario, with the majority of the jobs being generated in the global south.

98. **Improved transparency throughout the plastic life cycle is required to enable sound policy development.** Improved knowledge and information on the chemical content and additives of plastics will be necessary to strengthen recycling and ensure the safety of polymers and products.[2] Meanwhile, current information on production volumes, trade and fates of plastics is fragmented. For example, several studies have highlighted the lack of robust data on the fate of exported textiles, beyond anecdotal evidence of textiles being reused, downcycled or dumped in landfills and informal dumpsites.[104, 105]

99. **A globally aligned set of policy interventions can end plastic pollution.** A recent OECD report suggests an ambitious set of globally coherent policy mixes across the plastic life cycle can virtually eliminate mismanaged plastics and plastic leakage to the environment by 2040 and reduce plastic waste generation by 25 per cent compared to a 2020 baseline.[1] The scenarios assume different implementation rates across regions and find that measures to improve circularity are likely to contribute to economic growth. At the same time investments in waste management are likely to constitute a significant cost, estimated to 0.5 per cent of global GDP by 2040, with developing countries shouldering more of the burden. These estimates do not account for the benefits gained from addressing plastic pollution, including reduced adverse impacts to human health, the environment and livelihoods, and reduced greenhouse gas emissions.

1. Reduce and simplify the problem

100. **Upstream measures towards sustainable consumption and production levels** for plastics can be implemented through various regulatory, fiscal, voluntary and information measures that may work in tandem.

101. **Plastic production freezes, caps and production reduction targets may contribute to route plastic use to essential and high-value uses,** and drive a shift towards non-plastic substitutes and new product models for low-value uses of plastics.[31] Any caps or targets would require careful consideration, and robust knowledge for the establishment of baselines, differentiation between sectors or polymers, for instance prioritizing specific sectors, and potential exemptions for essential uses.[31]

102. **Removal of fossil fuel subsidies could reduce demand for virgin plastics** and drive investment in alternative plastics, non-plastic substitutes and business models due to increased competitiveness.[106] There is currently limited aggregated information on the scale of subsidies benefiting plastics production across the value chain, with data primarily covering subsidies for fossil fuels as a whole.[107]

103. **Taxes (or restrictions) on the purchase of virgin plastic feedstock and plastic-containing products for manufacturers of plastic packaging could provide a clear incentive for businesses to use less virgin plastic in production of packaging and products.** Analysis by OECD[38] suggests that increasing a tax at the global scale on plastic packaging linearly to $1,000/ton by 2030 and $2,000/ton by 2060 would roughly double the cost of plastic and could aid in decreasing plastic consumption, increase demand for recycled plastic and enhance investment in collection and recycling infrastructure. For the introduction of taxes, a country-specific economic appraisal and impact assessment would be required to determine the optimum taxation levels and rates of increase. To accommodate specific country circumstances, taxes could be avoided if other, equally effective instruments are found to reduce the use of virgin plastics equally.

104. **Eliminating products by rethinking design and purpose may provide another avenue for reduction.** It is economically feasible to reduce the consumption of short-lived plastic products by 30 per cent by 2040 while respecting the needs of a growing population and economy.[92] Eliminating problematic and unnecessary plastic products is best achieved by rethinking the design and purpose of products to "design out" problematic or unnecessary plastic use as well as hazardous chemicals and "design in" more sustainable alternatives to virgin plastics.

105. **Non-plastic substitutes and alternatives to virgin plastics should be assessed using a life-cycle approach to ensure that they do not involve burden-shifting**. Examples of sustainable alternatives that demonstrate better results in life-cycle assessment studies compared to single-use virgin plastics include reusable options and products with a high recycled content.[35]

106. **Chemical and product simplification** can enable greater recycling rates and reduce environmental and health impacts of plastics. Chemical simplification entails reducing the number, both in terms of compounds and volumes of additives in plastics, including the phase out of problematic and hazardous chemicals. Product simplification entails avoiding product components that cannot be easily separated and recycled, as well as reducing resource intensity – that is, making more with less.[108]

107. **Develop international guidance, standards and controls for additives and chemicals of concern**. Identifying hazardous chemicals in plastics and implementing controls and appropriate management could reduce harm to humans and the environment, as well as increasing safe reuse of plastic products and their recyclability. Ongoing work to this effect includes the new listings of chemicals under the Stockholm Convention and the developments of amendments to annexes II, VIII and IX of the Basel Convention to establish further controls on transboundary movements of plastic waste.

108. **Recycled content requirements or targets can increase the value and demand for recycled content,** as well as drive innovation in collection and recycling technologies. Increased use of recycled content can contribute to keep plastics in the economy for longer, increase the value of end-of-use plastics, reducing the chances of plastics being lost to the environment or ending up in landfills or subject to open burning or incineration.

2. Improve circularity of materials and products

109. **Accelerating design for reuse and recycling through harmonized criteria and standards.** Almost 80 per cent of short-lived plastic products cannot be recycled in an economically viable manner due to design decisions such as the inclusion of additives, combinations of materials or size.[109] Similarly, very few products are designed to be reused. Implementing design criteria or standards to reduce polymer diversity, use of additives, reinforce design formats that are reusable and recyclable, and standardize formats for reuse can improve profitability and drive recycling and reuse rates.

110. **Clear plastic labelling and/or other methods of information transfer on plastic polymers and chemical additives** can help to distinguish between plastics and reduce the risk of contamination of waste flows. Labelling aims to identify chemical exposures and risks, which can then be used by regulators to create measures that adequately safeguard human and environmental health. Consumers can also use this information to make informed purchasing decisions to protect themselves from plastic chemical exposure or demand safer products. Digital product passports based on blockchain technologies are being tested to improve traceability of products and their contents.[xi]

111. **Foster design for circularity for reuse and recycling by considering the need for standardized rules and labelling**, as well as information needs and economic incentives. Consistent labelling of materials, such as the use of specific symbols and colors for particular types of plastic, can enhance efficiency in the collection and sorting markets. Clear labelling can drive market growth and innovation by generating demand for increased circularity, driving investment and incentives for businesses and producers to conform.

112. **17 per cent of short-lived plastics can be replaced with sustainable substitutes.** Such replacements will require use of life-cycle analyses to account for the trade-offs between materials. Estimates suggest replacing flexible plastics with sustainably sourced paper could reduce greenhouse gas emissions by 25 per cent, assuming the plastic would be mechanically recycled, landfilled or incinerated at the end of use.[45]

113. **Extended producer responsibility (EPR) systems have been introduced in a number of countries with the aim of addressing plastic pollution.** EPR assigns responsibility for the impacts of products across the life cycle to the producers of the products. Typically, EPR schemes aim to internalize the impacts generated into the price of products by making producers responsible for the costs of collecting, managing and treating products at the end of use. Currently, EPR systems are largely implemented on the national or sub-national level, though global EPR systems have been proposed to hold producers and brand owners responsible for products traded internationally and to strengthen harmonization of regulations across borders.

114. **EPR schemes can take different formats and may be led by government agencies or private sector organizations in the form of producer responsibility organizations (PROs).**[110] Common formats for EPR schemes are take-back requirements, eco-modulation, and deposit-refund systems. Take-back requirements hold producers responsible for the collection and treatment of their goods at the end of use. Eco-modulation describes fees charged based on the weight, type of plastic and level of recyclability, whereas deposit return systems (DRS) entail consumers paying a deposit upon purchase which is reimbursed upon the return of the packaging to the producer. EPR schemes may be voluntary or mandatory. Voluntary fees are typically part of a company's corporate social responsibility program and may be administered by a PRO, whereas mandatory EPR schemes are typically regulated by a government, though the organization may be managed through a PRO or directly by a government or subsidiary body.

115. **Policies that directly target product characteristics (such as weight, recyclability, etc.) provide the most direct incentives for eco-design changes** according to a study of 395 existing extended producer responsibility schemes around the world.[111] The effectiveness of extended producer responsibility schemes in meeting reuse and recycling targets also tends to increase when extended producer responsibility is coupled with economic instruments such as landfill and incineration taxes, disposal bans for certain products or materials, packaging taxes and pay-as-you-throw schemes.[112] Eco-modulation of fees should also be considered. The eco-modulated fees should include the net costs associated with the collection, sorting and recycling of a material stream, thus providing the incentive to use materials with more favorable recycling economics.

3. Expand recycling and safely manage wastes

116. **Ensuring the environmentally sound management (ESM) of plastic wastes**, including minimization, improving collection, sorting, recycling and disposal of plastics is a key measure to prevent plastic pollution. Safe disposal is also critical to limit chemical pollution and releases from dumpsites and mismanaged engineered landfills. The recently updated Basel Convention Technical Guidelines on the Environmentally Sound Management of Plastic Wastes (UNEP/CHW.16/6/Add.3/Rev) provide a framework for comprehensive management of plastic wastes.

[xi] E.g., see the CIRPASS Digital Product Passport project for more information https://cirpassproject.eu/

117. **Ending plastic pollution will require increased investment in waste collection.** It is estimated that 22 per cent (47 million metric tons) of total annual plastic waste globally is currently left uncollected and that this figure could grow to 34 per cent (143 million metric tons) by 2040 under a business-as-usual scenario. Approximately 4 billion people will need to be connected to collection services by 2040, which requires connecting approximately 500,000 people to collection services per day, every single day until 2040, the majority of them in middle-/low-income countries.[92]

118. **Mechanical recycling** (collecting, cleaning, chipping and remelting of thermoplastics**) is the more sustainable option**; its technology is proven, it can be managed at a profit, and it emits 50 per cent less greenhouse gas emissions per metric ton of plastic product than chemical recycling.[92,113]

119. **Doubling the global mechanical recycling capacity** can cover ~33 per cent of the total plastics volumes, considering actions of reduce, substitute, design and collection are implemented in parallel.[15] Mechanical recycling has the potential to reduce the total system cost in $/metric ton of plastic (e.g., closed loop including collection and sorting costs) by $80 to $300 per metric ton, depending on the region and compared to non-circular life cycles.[15] Scaling up recycling requires adequate sorting and collection of plastic wastes, and will require substantial investments in waste management infrastructure, especially in developing countries.[1] Regarding greenhouse gas emissions, mechanical recycling emits ~60 per cent fewer emissions than controlled incineration on a per metric ton basis.[15] Only the elimination of plastic in the design or reuse schemes is more beneficial when it comes to greenhouse gas emissions.

120. **Increased investments in recycling technology and capacity** will be required to improve the effectiveness of mechanical recycling. Mechanical recycling requires well-sorted, high-quality materials with limited impurities and additives. The material degradation from the treatment of the materials means that virgin materials need to be included to achieve the desired properties of the plastic materials. Material losses in the recycling process are estimated to 25 per cent.[92]

121. **Concerns over chemical contamination of recycled plastic resins remain to be addressed.** Studies have identified hazardous chemicals, including chemicals already banned, in new products manufactured with recycled plastic content. This includes sensitive uses, such as food contact materials and toys. A study of recycled pellets from 13 countries identified 625 compounds, with the majority of the identified chemicals being associated with pesticides, pharmaceuticals and industrial compounds[114]. Improving recycling will therefore require changes across the value chain, from avoiding toxic and hazardous additives in the first place, improved information of chemical content, and the safe treatment of contaminated wastes, including electrical wastes and chemical containers to avoid entry into recycling streams.

122. **Chemical recycling encompasses a range of technologies, and few, if any, facilities are operating at scale.[115]** Plastic-to-plastic (P2P), or selective, chemical recycling describes chemical processes under development where certain plastic wastes are converted into feedstock for use to produce virgin-like plastics. [116] There is currently insufficient data and documentation of the potentials and impacts of these technologies.[16] Some estimates suggest P2P recycling would account for 5 per cent of total recycling volume by 2040, addressing materials that cannot otherwise be recycled.[15,45] Chemical recycling tends to be energy intensive and should only be used when the overall environmental profile is comparable to or better than other proven management options.[15,116]

123. **Compostable plastic products may be part of the solution for very specific applications provided adequate standards are enforced**. Under controlled conditions, compostable plastic can degrade fully into carbon dioxide, biomass and water compliant with relevant standards. Such plastic can be valuable for targeted applications such as bin liners for collection of organic waste destined for composting, if coupled with the relevant collection and composting infrastructure to ensure that it is composted in practice.[117] Unless used in compliance with adequate standards, however, biodegradable plastics carry a high risk of microplastic pollution.

124. **Minimize end-of-life plastic disposal**. Landfill and incineration charges (e.g., taxes and tipping fees) can direct waste upward in the waste hierarchy towards recovery and recycling by giving the other options a monetary benefit. In OECD countries, the introduction of a tax on waste sent to landfill has prompted a marked decrease in the volume of material being disposed of in landfills and an increase in material recovery facilities and mechanical and biological treatment facilities.[118]

125. **Prevent the export of plastic waste to nations with insufficient capacity to manage that waste** (in line with the Basel Convention plastic waste amendments and prior informed consent (PIC)

procedure for the transboundary movements (TBM) of waste)[xii]. Studies on trade bans or restrictions on plastic waste exports to countries that lack waste management capacity have shown that, in the short term, the ban significantly improves indicators of environmental impact, albeit contributed to global warming.[119]

4. Environmentally sound cleanups and remediation

126. **Measures are needed for responsible cleanup of existing plastic pollution.** While cleanup is considered the least cost-effective measure to address plastic pollution compared to upstream prevention, remediation of existing pollution is documented to have positive impacts on biota and habitats[120].

127. **Developing standards and best practices for the conduct of cleanup activities and use of cleanup technologies** can contribute to maximize the cost-efficiency and environmental benefits from cleanups, whilst avoiding pitfalls[121]. Indiscriminate removal of plastic pollution can cause harm due to bycatch and disturbance of habitats, and without plans for the fate of the collected materials may result in the collected plastics ending up back in the environment[122].

128. **Foster innovation in technologies for capturing leaked plastic.** Technologies for the collection of plastics, including microplastics, is an emerging area, along with new tools and approaches for preventing plastic leakage (e.g., the development of traps and sensors in stormwater drains that can help capture plastic waste).[123]

129. **Capture leaked microplastics by enhancing collection and management systems.** Better product design and selection should be the priority in reducing microplastic production and consumption; however, the use of technologies to collect and remediate microplastic pollution efficiently and prevent microplastics from entering the wider environment, such as filtering devices on taps and lint capture devices in clothes driers, can be beneficial. Consideration should be given to how such collected microplastic waste is then appropriately managed.

5. The importance of trade in the plastics economy

130. **Trade is an important component of the plastics system.** Global trade in plastics has been estimated to have reached a total value of 1.2 trillion USD in 2021.[124] This is likely an underestimation, given the challenges of estimating the value and volume of "hidden" plastics embedded in products, including packaging.

131. **Trade occurs at every step of the plastics life cycle and has a broad geographic spread** – virtually all countries are importers of plastic in one form or another, and many are also exporters.[125]

132. **Plastic trade flows are relevant to plastic pollution for two main reasons.** First, trade adds to the waste management burden that importing countries face and contributes to the spread of products responsible for microplastic pollution. Secondly, trade in plastic waste to countries with inadequate waste management capacity can exacerbate leakage of plastics into the environment.[125]

133. **Trade-related policies and measures,** and cooperation on trade, can contribute to addressing plastic pollution.[126] Trade-related policies that promote a circular plastics economy are present at all stages of the life cycle.[127] At the WTO, the 78 DPP co-sponsors have been exploring how trade and trade-related plastic measures could be harnessed to contribute to efforts to address plastic pollution. The group's Survey of trade and trade-related plastic measures (INF/TE/IDP/W/11) has identified more than 220 measures adopted by 85 WTO Members, mostly from developing Members. The results and related work have served as basis for the WTO MC13 Ministerial Statement on Plastic Pollution and Environmentally Sustainable Plastics Trade (WT/MIN(24)/14).

6. Opportunities moving forward

134. **A 96 per cent reduction in plastic leakage levels is possible.** According to an OECD analysis,[1] a comprehensive and coordinated approach delivered by reducing demand and production towards sustainable levels, accelerating reuse, circularity and recycling, and closing leakage pathways could cut plastic waste generation by a quarter under the baseline, virtually eliminate mismanaged plastics and reduce the volume of plastics entering the environment to 1.2 Mt by 2040; reduce primary plastic production by 14 per cent, production of short-lived packaging by 21 per cent and reduce greenhouse gas emissions from the plastic life cycle by 41 per cent.

[xii] See the Basel Convention website at https://basel.int/ for more information.

135. **Early action may incur larger capital macroeconomic costs in the short term, but will achieve substantially greater health, environmental and climate benefits**. The OECD report found that delaying ambition from 2040 to 2060 could limit the impacts of implementation on gross domestic products to 2040, but could also impose larger burdens on future generations as levels of mismanaged and leaked plastics to the environment would be significantly higher. Delaying ambition to 2060 would result in 38 million tonnes more mismanaged plastics over the timespan 2020-2040 compared to an accelerated timeline.[1]

136. **A comprehensive approach including policy measures targeting all stages of the life cycle would limit the costs of the transition**; by comparison, analyses show that policy packages that focus on waste management are associated with increasing waste management costs, investment needs as well as technical difficulties in eliminating plastic pollution.[1,16,37] Savings would occur especially in developing countries, where the largest growth in plastic waste generation is expected in coming years in a business-as-usual scenario.[1,37]

137. **An additional 700,000 jobs can be created across the value chain by 2040.** According to an International Resource Panel report[103], a systems change scenario would create net direct employment across the life cycle by 2040 equivalent to 700,000 jobs compared to a business-as-usual scenario, resulting in a total of 12 million additional jobs across the life cycle. Jobs would be redistributed among sectors and regions: Almost all the job growth would occur in middle- and low-income countries, primarily in reuse schemes, new delivery models and production of compostable alternatives, while job losses would occur in virgin plastic production, as well as in formal and informal collection, owing to a smaller volume of waste.

138. **Greenhouse gas emissions would be reduced.** Reuse schemes could decrease life cycle greenhouse gas emissions by 60 to 80 per cent when compared to single-use plastic products. Improving the design of plastic products and packaging for recycling could expand the share of economically recyclable plastic from today's 21 per cent to 54 per cent by 2040, by improving its profitability from $120 per metric ton to $240 per metric ton.[92] This could reduce greenhouse gas emissions by 48 per cent when comparing recycling versus landfilling plastic waste.

139. **Governments will reap net savings from reducing plastic waste.** In terms of costs, delivery of a systems change as outlined in the International Resource Panel report would result in a net saving of $70 billion for governments over the period 2021–2040, mainly because of the reduced volume of plastic waste requiring end-of-life treatment.[92] Savings would occur mainly in high-income countries (where current costs are higher), while net costs are expected in other income groups. Table 3 provides further details of the change in expected costs for governments for the period 2021–2040, by income group.

Table 3
Total change in expected government costs for the period 2021–2040, by income group
(Billions of United States dollars)

	Comparison, system change versus business-as-usual				
	Net present value of costs for governments[a]				
	High income	*Upper middle income*	*Lower middle income*	*Lower income*	*Total*
Formal collection	-107	-16	1	6	-116
Formal sorting	-7	11	3	-0	7
Thermal treatment	-19	0	–	–	-18
Engineered landfills	-4	3	2	1	2
Substitute – paper – waste management (end of life)	14	4	2	0	20
Substitute – coated paper – waste management (end of life)	8	3	1	0	13
Substitute – compostables – waste management (end of life)	7	9	4	1	20
Total	**-108**	**14**	**14**	**8**	**-72**

[a] At a discount rate of 3.5 per cent.

Source: The Pew Charitable Trusts and SYSTEMIQ, *Breaking the Plastic Wave: A Comprehensive Assessment of Pathways towards Stopping Ocean Plastic Pollution: Summary Report* (2020).

Notes

[1] OECD, *Towards Eliminating Plastic Pollution by 2040. A Policy Scenario Analysis* (Nov. 2023)

[2] M. Wagner and others, *State of the science on plastic chemicals - Identifying and addressing chemicals and polymers of concern* (2024), http://dx.doi.org/10.5281/zenodo.10701706.

[3] P.J. Landrigan, and others, "The Minderoo-Monaco Commission on plastics and human health", *Annals of Global Health*, vol. 89, no. 1 (2023).

[4] M. MacLeod, and others, "The global threat from plastic pollution", *Science*, vol. 373, no. 6550 (2021), pp. 61-65.

[5] L. Persson and others, "Outside the safe operating space of the planetary boundary for novel entities", *Environmental science & technology,* vol. 56, no.3 (2022), pp. 1510-1521.

[6] N.J. Beaumont and others, "Global ecological, social and economic impacts of marine plastic", *Marine Pollution Bulletin,* vol. 142 (May 2019), pp. 189–195.

[7] H.V. Ford, and others "The fundamental links between climate change and marine plastic pollution", *Science of the Total Environment,* vol. 806 (2022), p. 150392.

[8] J. Zheng and S. Suh, "Strategies to reduce the global carbon footprint of plastics", *Nature climate change,* vol. 9, no. 5 (2019), pp. 374-378.

[9] W.W.Y. Lau and others, "Evaluating scenarios toward zero plastic pollution", *Science,* vol. 369, no. 6510 (2020), pp. 1455-1461.

[10] S.B. Borrelle and others, "Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution", *Science,* vol. 369, no. 6510 (2020), pp. 1515-1518.

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

[12] C. Velis and E. Cook, "Mismanagement of Plastic Waste through Open Burning with Emphasis on the Global South: A Systematic Review of Risks to Occupational and Public Health", *Environmental Science and Technology*, vol. 55, no. 11 (June 2021), pp. 7186–7207.

[13] UN-Habitat and NIVA, *Leaving no one behind - How a global instrument to end plastic pollution can enable a just transition for the people informally collecting and recovering waste* (UN-Habitat, 2022)

[14] F. Vidal and others, "Designing a circular carbon and plastics economy for a sustainable future", *Nature* vol. 626, no. 7997 (2024), pp. 45-57.

[15] The Pew Charitable Trusts and SYSTEMIQ, *Breaking the Plastic Wave: A Comprehensive Assessment of Pathways towards Stopping Ocean Plastic Pollution: Summary Report* (2020).

[16] UNEP, *Turning off the Tap. How the world can end plastic pollution and create a circular economy*. (UNEP, 2023)

[17] M. Bachmann, and others. "Towards circular plastics within planetary boundaries", *Nature Sustainability,* vol. 6, no. 5 (2023), pp. 599-610.

[18] UNEP, *Basel Convention technical guidelines on the environmentally sound management of plastic wastes* (UNEP, May 2023)

[19] International Organization for Standardization (ISO), *ISO 472:2013(en) Plastics — Vocabulary* (ISO, 2013)

[20] For an elaboration on different definitions of microplastics and their implications, see I. Rognerud and others, *Addressing microplastics in a global agreement to end plastic pollution* (Nordic Council, 2023)

[21] ISO, *TR 21960:2020, Plastics – Environmental aspects – State of knowledge and methodologies* (ISO, 2020)

[22] GESAMP, *Sources, fate and effects of microplastics in the marine environment: a global assessment* (Kershaw, P. J., ed.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, 2015). Rep. Stud. GESAMP No. 90, 96 p.

[23] S.M. Brander and others, "Sampling and quality assurance and quality control: a guide for scientists investigating the occurrence of microplastics across matrices", *Applied Spectroscopy,* vol. 74, no. 9 (2020), pp. 1099-1125.

[24] UNCTAD, *Plastic Pollution. The pressing case for natural and environmentally friendly substitutes to plastics* (Geneva, United Nations, 2023)

[25] C. V. Stevens, *Bio-Based Packaging: Material, Environmental and Economic Aspects* (John Wiley & Sons, 2021).

[26] J-G.Rosenboom, R. Langer, and G. Traverso. "Bioplastics for a circular economy", *Nature Reviews Materials,* vol. 7 no. 2 (2022), pp. 117-137.

[27] N. Singh and others, "Sustainable materials alternative to petrochemical plastics pollution: A review analysis", *Sustainable horizons,* vol. 2 (2022), p. 100016.

[28] Science Advice for Policy by European Academies (SAPEA), *Biodegradability of plastics in the open environment.* (Berlin, SAPEA, 2020). doi:10.26356/biodegradabilityplastics

[29] I.E. Napper and R.C. Thompson, "Environmental deterioration of biodegradable, oxo-biodegradable, compostable, and conventional plastic carrier bags in the sea, soil, and open-air over a 3-year period." *Environmental science & technology* vol. 53 no. 9 (April 2019), pp. 4775-4783.

[30] D. Purkiss and others, "The Big Compost Experiment: Using citizen science to assess the impact and effectiveness of biodegradable and compostable plastics in UK home composting", *Frontiers in Sustainability,* vol. 3 (2022), p. 942724.

[31] N. Simon and others, "A binding global agreement to address the life cycle of plastics", *Science*, vol. 373, no. 6550 (2021), pp. 43-47.

[32] M. W. Ryberg and others, "Global environmental losses of plastics across their value chains", *Resources, Conservation and Recycling*, vol. 151 (Dec. 2019).

[33] L. Laurin, "Overview of LCA—history, concept, and methodology", *Encyclopedia of Sustainable Technologies* (2017), pp. 217–222.

[34] S.A. Miller, "The capabilities and deficiencies of life cycle assessment to address the plastic problem", *Frontiers in Sustainability,* vol. 3 (2022), p. 1007060.

[35] UNEP, *Addressing Single-Use Plastic Products Pollution Using a Life Cycle Approach* (Nairobi, 2021).

[36] Plastics Europe, *Plastics – The Facts 2021: An Analysis of European Plastics Production, Demand and Waste Data* (Brussels, 2021).

[37] OECD, *Towards eliminating plastic pollution by 2040: A scenario analysis* (Paris, OECD Publishing, forthcoming).

[38] OECD, *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options* (Paris, OECD Publishing, 2022).

[39] UNEP, *Drowning in Plastics: Marine Litter and Plastic Waste Vital Graphics* (Nairobi, 2021).

[40] R. Geyer, R. J. Jambeck and K. L. Law, "Production, use, and fate of all plastics ever made", *Science Advances*, vol. 3, no. 7 (July 2017).

[41] UNEP, *Information submitted by the Secretariat of the Basel, Rotterdam and Stockholm conventions* (UNEP/PP/INC.3/INF/4, 2023)

[42] UNEP and BRS Secretariat, *Chemicals in Plastics - A Technical Report* (Geneva, UNEP, 2023)

[43] Ellen MacArthur Foundation, The Ellen MacArthur Foundation's Plastics Initiative 2024 Recycling Rate Survey results summary. Available at https://emf.thirdlight.com/link/6bnvju827y0v-rr0pqw/@/. See table 1, pp. 4–5.

[44] E. Gilman and others, "Highest risk abandoned, lost and discarded fishing gear", *Scientific Reports,* vol. 11, no. 1 (2021), p. 7195.

[45] UNEP, *Turning off the Tap. How the world can end plastic pollution and create a circular economy*. (UNEP, 2023)

[46] K. Richardson, B. D. Hardesty and C. Wilcox, "Estimates of fishing gear loss rates at a global scale: A literature review and meta-analysis", *Fish and Fisheries*, vol. 20, no. 6 (Nov. 2019), pp. 1218–1231.

[47] International Maritime Organization, "Marine litter". Available at https://www.imo.org/en/MediaCentre/HotTopics/Pages/marinelitter-default.aspx.

[48] Food and Agriculture Organization of the United Nations, *Assessment of Agricultural Plastics and Their Sustainability: A Call for Action* (Rome, 2021).

[49] Textile Exchange, *Corporate Materials Market report 2023* (Textile Exchange, 2023), available at: https://textileexchange.org/app/uploads/2023/11/Materials-Market-Report-2023.pdf

[50] European Environment Agency (EEA), *EU exports of used textiles in Europe's circular economy* (EEA, 2023)

[51] Z. Gao and others, "Research progress on microplastics in wastewater treatment plants: A holistic review", *Journal of Environmental Management,* vol. 325 (2023), p. 116411.

[52] T. Schell and others, "Fate of microplastics in agricultural soils amended with sewage sludge: Is surface water runoff a relevant environmental pathway?", *Environmental Pollution,* vol. 293 (2022), p. 118520.

[53] L.J. J. Meijer and others, "More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean", *Science Advances*, vol. 7, no. 18 (April 2021).

[54] UNEP, *From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution* (Nairobi, 2021).

[55] M. Bergmann and others, "Vast Quantities of Microplastics in Arctic Sea Ice – A Prime Temporary Sink for Plastic Litter and a Medium of Transport". In Juan Baztan and others, *Fate and Impact of Microplastics in Marine Ecosystems* (Elsevier Inc., 2017).

[56] P.J. Landrigan and others. "The Minderoo-Monaco Commission on plastics and human health", *Annals of Global Health,* vol. 89, no. 1 (2023).

[57] A. Vethaak and J. Legler, "Microplastics and human health: knowledge gaps should be addressed to ascertain the health risks of microplastics", *Science*, vol. 371, no. 6530 (Feb. 2021), pp. 672–674.

[58] V. Foulon and others, "**Colonization of polystyrene microparticles by Vibrio crassostreae: light and electron microscopic investigation**", *Environmental Science and Technology,* vol. 50, no. 20 (Oct. 2016), pp. 10988–10996.

[59] K.D. Cox and others, "Hidden Consumption of Microplastics", *Environmental Science and Technology*, vol. 53, no. 12 (June 2019), pp. 7068–7074.

[60] S. Giri and others "Microplastics contamination in food products: Occurrence, analytical techniques and potential impacts on human health", *Current Research in Biotechnology* (2024): 100190.

[61] A. Markic and others, "Plastic ingestion by marine fish in the wild", *Critical Reviews in Environmental Science and Technology*, vol. 50, no. 7 (July 2019), pp. 657–697.

[62] Nanoplastics are commonly defined as plastic particles smaller than 1 nanometre (<1 µm)

[63] N. Qian and others, "Rapid single-particle chemical imaging of nanoplastics by SRS microscopy." *Proceedings of the National Academy of Sciences*, vol. 121, no. 3 (2024), e2300582121.

[64] N. Aurisano and others, "Chemicals of concern in plastic toys", *Environment International*, vol. 146 (Jan. 2021).

[65] D. Montano, "Chemical and biological work-related risks across occupations in Europe: a review", *Journal of Occupational Medicine and Toxicology*, vol. 9, article 28 (July 2014).

[66] A.C. Ryan and others, "Transport and deposition of ocean-sourced microplastic particles by a North Atlantic hurricane", *Communications Earth & Environment,* vol. 4, no.1 (2023), p. 442.

[67] S. O'Brien and others, "There's something in the air: a review of sources, prevalence and behaviour of microplastics in the atmosphere", *Science of the Total Environment,* vol. 874 (2023), p. 162193.

[68] K. S. Verma and others, "Toxic Pollutants from Plastic Waste – A Review", *Procedia Environmental Sciences*, vol. 35 (2016), pp. 701–708.

[69] K-T, Rim, "Occupational exposure to mixtures and toxic pathways prediction for workers' health", *Molecular & Cellular Toxicology,* vol.19, no.4 (2023), pp: 775-788.

[70] T.J. Woodruff, "Health Effects of Fossil Fuel–Derived Endocrine Disruptors," *New England Journal of Medicine,* vol. 390, no.10 (2024), pp: 922-933.

[71] A.O.C. Iroegbu and others, "Plastic Pollution: A Perspective on Matters Arising: Challenges and Opportunities", *ACS Omega*, vol. 6, no. 30 (July 2021), pp. 19343–19355.

[72] R. Dris and others, "A first overview of textile fibers, including microplastics, in indoor and outdoor environments", *Environmental Pollution*, vol. 221 (Feb. 2017), pp. 453–458.

[73] P. J. Kole and others, "Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment", *International Journal of Environmental Research and Public Health*, vol. 14, no. 10 (Oct. 2017).

[74] J. Flaws and others, *Plastics, EDCs and health: A guide for public interest organizations and policy-makers on endocrine disrupting chemicals & plastics* (Washington, Endocrine Society, 2020).

[75] J.C. Prata and others, "A One Health perspective of the impacts of microplastics on animal, human and environmental health", *Science of the Total Environment* 777 (2021), p. 146094.

[76] L.M. Thornton Hampton and others, "Research recommendations to better understand the potential health impacts of microplastics to humans and aquatic ecosystems", *Microplastics and Nanoplastics,* vol. 2, no. 1 (2022), p. 18.

[77] J. Lin and others, "Microplastics in Remote Coral Reef Environments of the Xisha Islands in the South China Sea: Source, Accumulation and Potential Risk", *Journal of Hazardous Materials,* (2024), 133872.

[78] X. Li and others, "Photoaged polystyrene microplastics result in neurotoxicity associated with neurotransmission and neurodevelopment in zebrafish larvae (Danio rerio)", *Environmental Research* (2024), 118524.

[79] E. Funke, L. Webb, and J. Wolinska. "The effect of microplastics on Daphnia fitness–Systematic review and meta-analysis", *Freshwater Biology* (2024).

[80] F.R. Khan and others, "An overview of the key topics related to the study of tire particles and their chemical leachates: From problems to solutions", *TrAC Trends in Analytical Chemistry* (2024): 117563.

[81] P. Boisseaux and others, "Deep dive into the chronic toxicity of tyre particle mixtures and their leachates", *Journal of Hazardous Materials* (2024), 133580.

[82] L. Chibwe and others, "A deep dive into the complex chemical mixture and toxicity of tire wear particle leachate in fathead minnow." *Environmental toxicology and chemistry,* vol. 41, no. 5 (2022), pp. 1144-1153.

[83] Z. Tian and others, "A ubiquitous tire rubber–derived chemical induces acute mortality in coho salmon", *Science,* vol. 371 no. 6525 (2021), pp. 185-189.

[84] M. Shen and others, "**(Micro) plastic crisis: un-ignorable contribution to global greenhouse gas emissions and climate change**", *Journal of Cleaner Production*, vol. 254, article 120138 (May 2020).

[85] L. E. Revell and others, "Direct radiative effects of airborne microplastics", *Nature,* vol. 598 (Oct. 2021), pp. 462–467.

[86] Y-L. Zhang, S-C. Kang and T-G. Gao, "Microplastics have light-absorbing ability to enhance cryospheric melting", *Advances in Climate Change Research*, vol. 13, no. 4 (June 2022), pp. 455–458.

[87] S.O. Andersen and others, "Narrowing feedstock exemptions under the Montreal Protocol has multiple environmental benefits", *Proceedings of the National Academy of Sciences*, vol. 118, no. 49 (Nov. 2021). https://doi.org/10.1073/pnas.2022668118

[88] See e.g., D. Zhang and others, “Plastic pollution in croplands threatens long-term food security”, *Global Change Biology*, vol. 26, no. 6 (June 2020), pp. 3356–3367; L. Han and others "Microplastics alter soil structure and microbial community composition." *Environment International* (2024): 108508.

[89] See e.g., L.J. Zantis and others, "Nano-and microplastics commonly cause adverse impacts on plants at environmentally relevant levels: A systematic review", *Science of the Total Environment*, vol 867 (April 2023); M.A. Ranauda and others "Microplastics affect soil-plant system: Implications for rhizosphere biology and fitness of sage (Salvia officinalis L.)." *Environmental Pollution* (2024): 123656.

[90] B. Worm and others, “Impacts of biodiversity loss on ocean ecosystem services”, *Science*, vol. 314, no. 5800 (Nov. 2006), pp. 787–790.

[91] J. Nikiema and Z. Asiedu, “A review of the cost and effectiveness of solutions to address plastic pollution”, *Environmental Science and Pollution Research,* vol. 29 (Jan. 2022), pp. 24547–24573.

[92] The Pew Charitable Trusts and SYSTEMIQ, *Breaking the Plastic Wave: A Comprehensive Assessment of Pathways towards Stopping Ocean Plastic Pollution: Summary Report* (2020).

[93] I. Rijk, M. van Duursen and M. van den Berg, *Health Costs That May Be Associated with Endocrine Disrupting Chemicals: An Inventory, Evaluation and Way Forward to Assess the Potential Socio-Economic Impact of EDC--Associated Health Effects in the EU* (Utrecht, Institute for Risk Assessment Sciences, 2016).

[94] UNEP, *Mapping of Global Plastics Value chain and Plastics Losses to the Environment: With a Particular Focus on Marine Environment* (Nairobi, 2018).

[95] An example of how necessary products could be identified, see Y. Ando and others "Product-based approach to sustainable plastic management focusing on consumers’ necessity of 50 daily-use products in Japan", *Journal of Cleaner Production*, vol. 418 (2023), p. 138234.

[96] Experience can be drawn from the impacts of climate mitigation measures on vulnerable populations, as elaborated in N. Jones, "Safeguarding against Environmental Injustice: 1.5 Degree Celsius Scenarios, Negative Emissions, and Unintended Consequences", *CCLR,* vol. 12 (2018), p. 23.

[97] X. Zhu, M.J. Hoffman, and C. Rochman, "A city-wide emissions inventory of plastic pollution", *Environmental Science & Technology* (2024).

[98] UNEP, “The New Plastics Economy Global Commitment”. Available at https://www.unep.org/new-plastics-economy-global-commitment.

[99] Back to Blue, “Plastic Management Index”. Available at https://backtoblueinitiative.com/plastics-management-index/.

[100] The WTO DPP is currently co-sponsored by 78 WTO Members and coordinated by Australia, Barbados, China, Ecuador, Fiji and Moroccos. The initiative, established in 2020, seeks to explore how the WTO could contribute to efforts to reduce plastics pollution and promote the transition to more environmentally sustainable trade in plastics. More at https://www.wto.org/english/tratop_e/ppesp_e/ppesp_e.htm.

[101] UNEP, *Third global monitoring report. Global monitoring plan for persistent organic pollutants under the Stockholm Convention Article 16 on effectiveness evaluation.* (Secretariat of the Basel, Rotterdam and Stockholm conventions, United Nations Environment Programme, Geneva, 2023).

[102] L. Persson, and others, "Outside the safe operating space of the planetary boundary for novel entities", *Environmental science & technology,* vol. 56, no. 3 (2022), pp. 1510-1521.

[103] International Resource Panel, *Policy options to eliminate additional marine plastic litter by 2050 under the G20 Osaka Blue Ocean Vision* (Nairobi, UNEP, 2021), quoting from The Pew Charitable Trusts and SYSTEMIQ, *Breaking the Plastic Wave: A Comprehensive Assessment of Pathways towards Stopping Ocean Plastic Pollution: Summary Report* (2020).

[104] European Environment Agency (EEA), *EU exports of used textiles in Europe’s circular economy* (EEA, 2023)

[105] K.L.Law and others, “The United States’ contribution of plastic waste to land and ocean”, *Science advances*, vol. 6, no. 4 (2020).

[106] J.P. Tilsted and others, "Ending fossil-based growth: Confronting the political economy of petrochemical plastics", *One Earth* (2023).

[107] R. Steenblik, *Subsidies and Plastic Production – An Exploration*, Working Paper (Graduate Institute Geneva, 2019)

[108] K. Kümmerer, J.H. Clark, and V.G. Zuin, "Rethinking chemistry for a circular economy", *Science*, vol. 367, no. 6476 (2020): pp. 369-370.

[109] UNEP, *Turning off the Tap. How the world can end plastic pollution and create a circular economy*. (UNEP, 2023)

[110] S. Lorang, Shari and others, "Achievements and policy trends of extended producer responsibility for plastic packaging waste in Europe", *Waste Disposal & Sustainable Energy,* vol. 4, no. 2 (2022), pp. 91-103.

[111] D. Kaffine and P. O’Reilly, “What have we learned about extended producer responsibility in the past decade? A survey of the recent EPR economic literature”, ENV/EPOC/WPRPW(2013)7/FINAL .

[112] E. Watkins and others, *EPR in the EU Plastics Strategy and the Circular Economy: A Focus on Plastic Packaging* (Brussels, Institute for European Environmental Policy, 2017).

[113] Y. Chen and others, Life cycle assessment of end-of-life treatments of waste plastics in China", *Resources, Conservation and Recycling,* vol. 146 (2019), pp. 348-357.

[114] E. Carmona and others, "A dataset of organic pollutants identified and quantified in recycled polyethylene pellets." *Data in Brief,* vol. 51 (2023): pp. 109740.

[115] R-X.Yang and others, "Thermochemical conversion of plastic waste into fuels, chemicals, and value-added materials: a critical review and outlooks", *ChemSusChem*, vol. 15, no. 11 (2022), p. e202200171.

[116] R.A. Clark and M.P. Shaver, "Depolymerization within a Circular Plastics System", *Chemical Reviews,* vol. 124 (2024), pp. 2617-2650.

[117] Based on: "New Plastics Economy Global Commitment: Commitments, Vision and Definitions" (Ellen MacArthur Foundation, 2020). Available at https://emf.thirdlight.com/link/pq2algvgnv1n-uitck8/@/preview/1?o.

[118] E. Watkins and others, "Policy approaches to incentivise sustainable plastic design", *OECD Environment Working Papers*, No. 149 (Paris, OECD Publishing, 2019).

[119] Z. Wen and others, "China's plastic import ban increases prospects of environmental impact mitigation of plastic waste trade flow worldwide", *Nature Communications,* vol. 12 (2021), pp. 1–9.

[120] S. Arabi, and A. Nahman, "Impacts of marine plastic on ecosystem services and economy: State of South African research", *South African Journal of Science,* vol. 116.5, no. 6 (2020), pp. 1-7.

[121] J. Falk-Andersson and others, "Cleaning up without messing up: maximizing the benefits of plastic clean-up technologies through new regulatory approaches", *Environmental Science & Technology,* vol. 57, no. 36 (2023), pp. 13304-13312.

[122] UNEP, *X-Press Pearl Maritime Disaster: Sri Lanka - Report of the UN Environmental Advisory Mission* (United Nations Environment Programme & United Nations Office for the Coordination of Humanitarian Affairs, 2021).

[123] G. Leone and others, "A comprehensive assessment of plastic remediation technologies", *Environment International,* vol. 173 (2023), p. 107854.

[124] See UNCTAD plastic trade database, at https://unctad.org/data-visualization/global-plastics-trade-reached-nearly-1.2-trillion-2021.

[125] D. Barrowclough, C. Deere-Birkbeck and J. Christen, *Global trade in plastics: insights from the first life cycle trade database*, UNCTAD/SER.RP/2020/12 (Dec. 2020).

[126] See OECD, Trade policies to promote the circular economy A case study of the Plastics value chain (Dec. 2023) at https://www.oecd-ilibrary.org/docserver/e36f2d91-en.pdf?expires=1707225910&id=id&accname=guest&checksum=96D7BF4113B6ED8635C5951214604A37, IISD *Trade-Related Policy Measures to Reduce Plastic Pollution : Building on the state of play (2023)*, available at https://www.iisd.org/system/files/2023-05/trade-policy-reduce-plastic-pollution-state-of-play.pdf ; and Carolyn Deere Birkbeck and Mahesh Sugathan, *How can international trade policy help tackle plastic pollution? Policy options and pathways*, TESS (2021), at https://snis.ch/wp-content/uploads/2020/01/2019_Littoz-Monnet_Working-Paper-7.pdf

[127] OECD, Trade policies to promote the circular economy A case study of the Plastics value chain (Dec. 2023) at https://www.oecd-ilibrary.org/docserver/e36f2d91-en.pdf?expires=1707225910&id=id&accname=guest&checksum=96D7BF4113B6ED8635C5951214604A37, p. 19.