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Plastic pollution: Pathways to net zero

A Center for Sustainability publication

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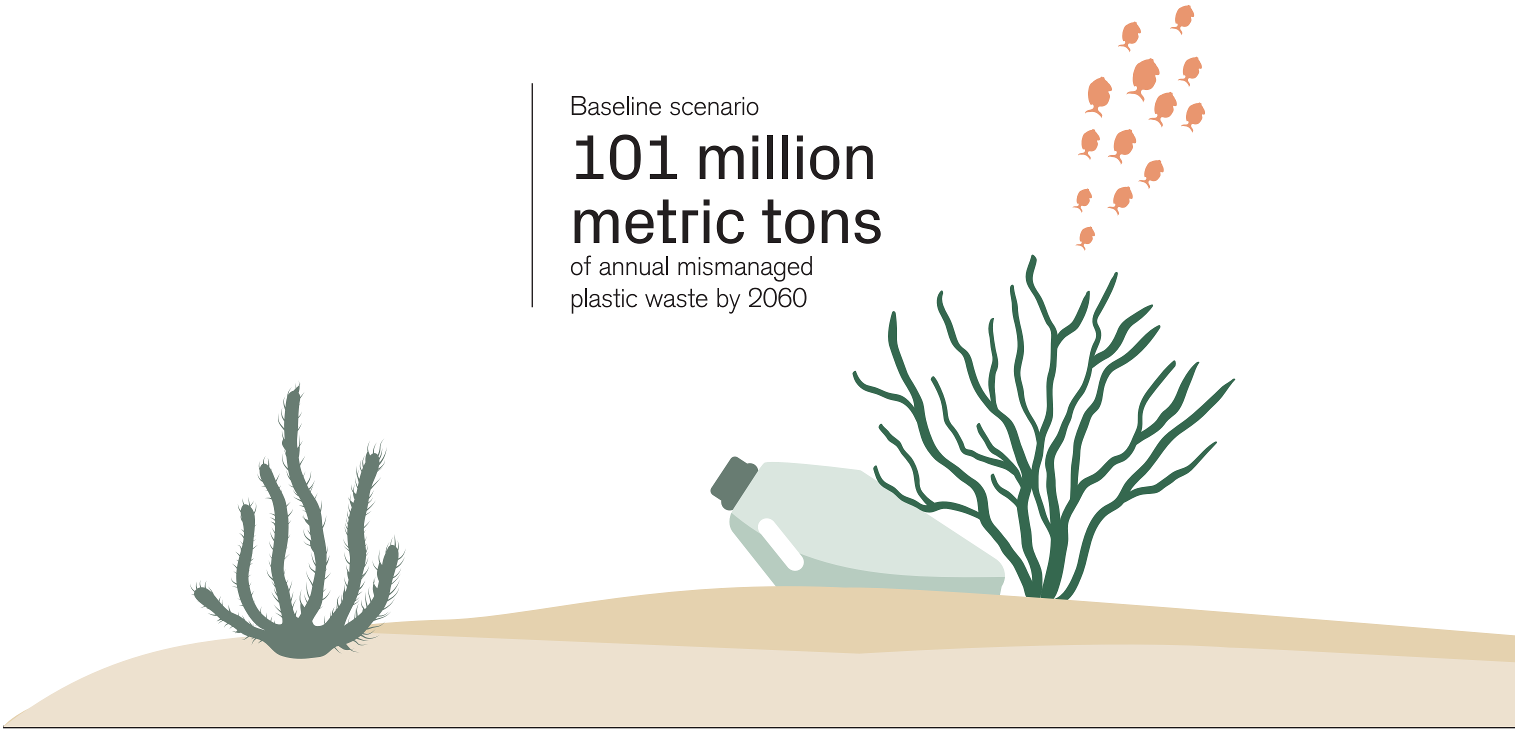

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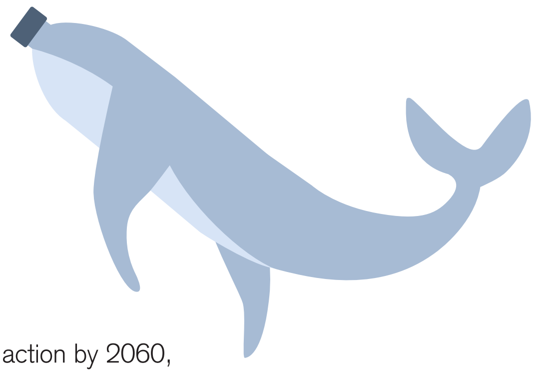

Without additional policy action by 2060, there could be more plastic metric tonnage than

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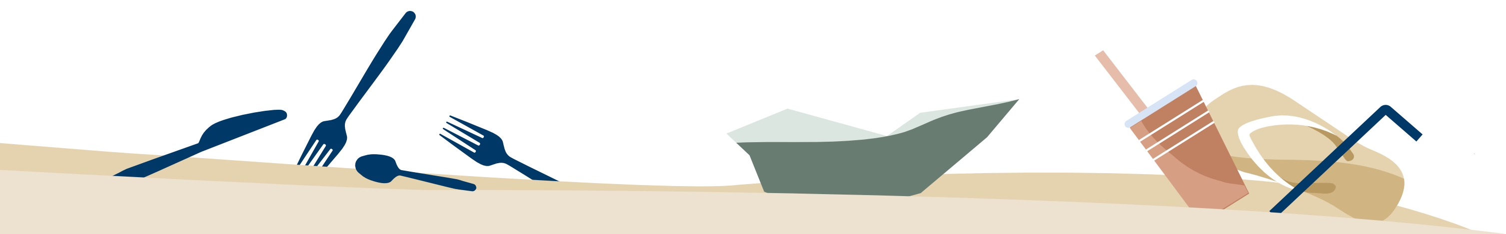


Foreword

Welcome to the latest report produced by the Credit Suisse Center for Sustainability (CfS).

This CfS report tackles a topic which is not only important, but is also accessible and understandable – plastic pollution. Whether it is plastic bottles bobbing in rivers or shopping bags floating freely in the street, we have all witnessed plastic pollution in one form or another.

While plastic pollution may be unsightly, plastic itself is an effective material. Whether it is ensuring food quality, encasing our consumer electronics or forming part of complex industrial machinery – plastic is pervasive in our economy.

This report therefore takes a balanced path – it explores the benefits as well as the costs of plastic across environment, biodiversity and social pillars. The main focus of the report is not to eliminate all plastic, but instead to ensure appropriate plastic disposal to minimize plastic's negative interaction with terrestrial and aquatic environments.

This report draws off the popular "net zero" climate movement and repurposes some of the movement's terminology and analytical tools to provide a prism through which to view plastic pollution.

The key contribution to the conversation on plastic pollution is the establishment of a Plastic Kaya Identity, which is a powerful approach that decomposes plastic pollution into multiple demographic, economic and social parameters. The Kaya Identity has transformed how we collectively tackle carbon emissions. It is our hope that its application in a plastic pollution context will be valuable.

We also borrow "net zero" concepts such as mitigation, adaptation and "bending the curve." These terms provide a disciplined analytical framework with which to assess policy responses and should be conceptually familiar to many of our readers. Various chapters are dedicated to assessing a number of options.

My colleagues and I are closely watching the second meeting of United Nations Environment Assembly's Intergovernmental Negotiating Committee. The Intergovernmental Negotiating Committee is, at the time of publication, meeting in Paris, France, to further formulate a global plastics treaty to end plastic pollution. We publish this report with an ambition to contribute constructively to this dialogue.

Emma Crystal
Chief Sustainability Officer
Credit Suisse

About the CfS

The Center for Sustainability (CfS) is a pillar of the Credit Suisse Research Institute (CSRI), our in-house think tank, which studies long-term economic developments that have a global impact on the financial services industry and beyond. The CfS aims to provide our clients and stakeholders with a deeper understanding of emerging sustainability topics as we bridge the perspectives of sustainability experts from across Credit Suisse to confront the challenges and opportunities faced by our planet and society. Also collaborating with leading external sustainability experts, we strive to elevate CfS content and engage more productively in the broader concept of environmental, social and governance themes.

Executive summary

In this paper, we are inspired by climate parallels and present a "net zero" concept for plastic pollution. To support our forecasting, we draw on a climate cornerstone – the Kaya Identity – and, in an innovation, adapt the Identity to forecast plastic pollution out to 2060. This enables us to decompose plastic usage, waste and pollution into composite demographic, economic and social drivers, which provides a unique insight into the future of plastic waste and the pathway to achieving net zero plastic waste.

According to the OECD, the world utilizes approximately 450 million metric tons of plastic a year, approximately 57 kilograms per person. Each year more than 350 million metric tons of plastic become plastic waste, of which approximately 80 million metric tons become mismanaged plastic waste, also termed plastic pollution. This plastic pollution is estimated to come at a significant social and environmental cost – at least USD 300 billion per annum, and, according to certain estimates, as high as USD 1,500 billion per annum. Utilizing our Plastic Kaya Identity, we find that, over the past 60 years, the plastic usage intensity of GDP has dominated both the growth in population and GDP per capita. For every dollar of GDP added to the global economy, the data suggest that an increasing amount of plastic was required.

We utilize the Plastic Kaya Identity to forecast future volumes of plastic pollution. Under a baseline scenario that extends current trends and does not assume additional policy action, we expect annual plastic waste to almost double from approximately 350 million metric tons to about 670 million metric tons by 2060. However, annual mismanaged plastic waste increases by a smaller proportion – from approximately 80 million metric tons to just over 100 million metric tons. We analyze additional more optimistic estimates driven off OECD-defined policy scenarios and provide sensitivity analysis to contextualize potential future changes in the plastic waste intensity of GDP and potential future changes in the volume of mismanaged plastic waste as a proportion of total plastic waste.

We update the infamous (and subsequently disproved) 2016 statement from an Ellen MacArthur Foundation paper that, by 2050, there would be more plastic metric tonnage than fish in the sea. With our revised dataset, we make an interesting – though less-sensational – claim that, without additional policy action by 2060, there could be more plastic tonnage than whale biomass in the sea.

To help us collectively avoid the ignominy of producing over 100 million metric tons of mismanaged plastic waste per annum, we delve again into our climate "net zero" playbook. We borrow the concepts of mitigation and adaptation, and assess their interaction with the Plastic Kaya Identity. For mitigation, we focus on the practical ways to decrease the plastic waste intensity of GDP. For adaptation, we acknowledge plastic's existence and focus on ways to reduce mismanaged plastic waste.

In terms of mitigation and reducing the plastic waste intensity of GDP, we note that legislative action to restrain plastic demand, while often effective, can have unintended consequences. For example, mandating a reduction in plastic food packaging could lead to greater food spoilage. We highlight research showing that sending just one kilogram of food waste to landfill has a similar carbon footprint to landfilling 25,000 500 milliliter plastic bottles.

We also note the severe limitations of bioplastics whose current market share is less than 1% of current plastic usage. We highlight their challenges, such as limited microbial degradation, high costs and complex ethics. In terms of adaptation, we note that enhanced waste management infrastructure has by far the greatest cost-benefit impact on reducing mismanaged plastic waste. We discuss the challenges involved in increasing recycling and identify an exorbitant cost differential between proactively removing plastic pollution from terrestrial and aquatic environments, and the more affordable prevention of plastic leakage.

Finally, we look ahead with cautious optimism. The negotiations for a global plastics treaty could yield the most significant sustainability-focused multilateral proposal since the Paris Agreement in 2015. After all, it was the Paris Agreement that inspired the race to net zero, and which provided the concepts that we have adopted and adapted to plastic pollution.

Tatiana Maksimova, Getty Images

Where we stand

Key points:

- Today, the world utilizes approximately 450 million metric tons of plastic a year, which is approximately 57 kilograms per person. Each year more than 350 million metric tons of plastic becomes plastic waste.
- Globally, approximately two-thirds of countries have adopted some form of legislation to regulate plastic bags and approximately a third have mandates for extended producer responsibility for single-use plastics, including deposit-refunds, product take-back and recycling targets.
- In March 2022, the United Nations Environment Assembly adopted a landmark resolution and initiated negotiations for a global plastics treaty to end plastic pollution. In what could be the most significant sustainability-focused multilateral proposal since the Paris Agreement in 2015, the resolution seeks a legally binding treaty by 2024.

Plastic usage and plastic waste

Plastic is ubiquitous in modern life from packaging to textiles to consumer products, which is testament to its broad range of applicability, value and durability. It is estimated that the primary plastics sector accounts for around USD 600–700 billion per year in revenues (UNEP, 2023, see References on page 44).

According to the OECD's 2022 Global Plastics Outlook Database (OECD, 2022a), today's world utilizes approximately 450 million metric tons of plastic a year. Each year more than 350 million metric tons of plastic become plastic waste, of which 40% comes from various forms of packaging, with consumer products and textiles each making up a further 10%–15% each. Thankfully, not all plastic waste is mismanaged and becomes plastic pollution. Sanitary landfills collect approximately 46% of global plastic waste, controlled incineration accounts for a further 17% and recycling collects 15%. This leaves 22% of plastic waste that is mismanaged – a total of almost 80 million metric tons a year.

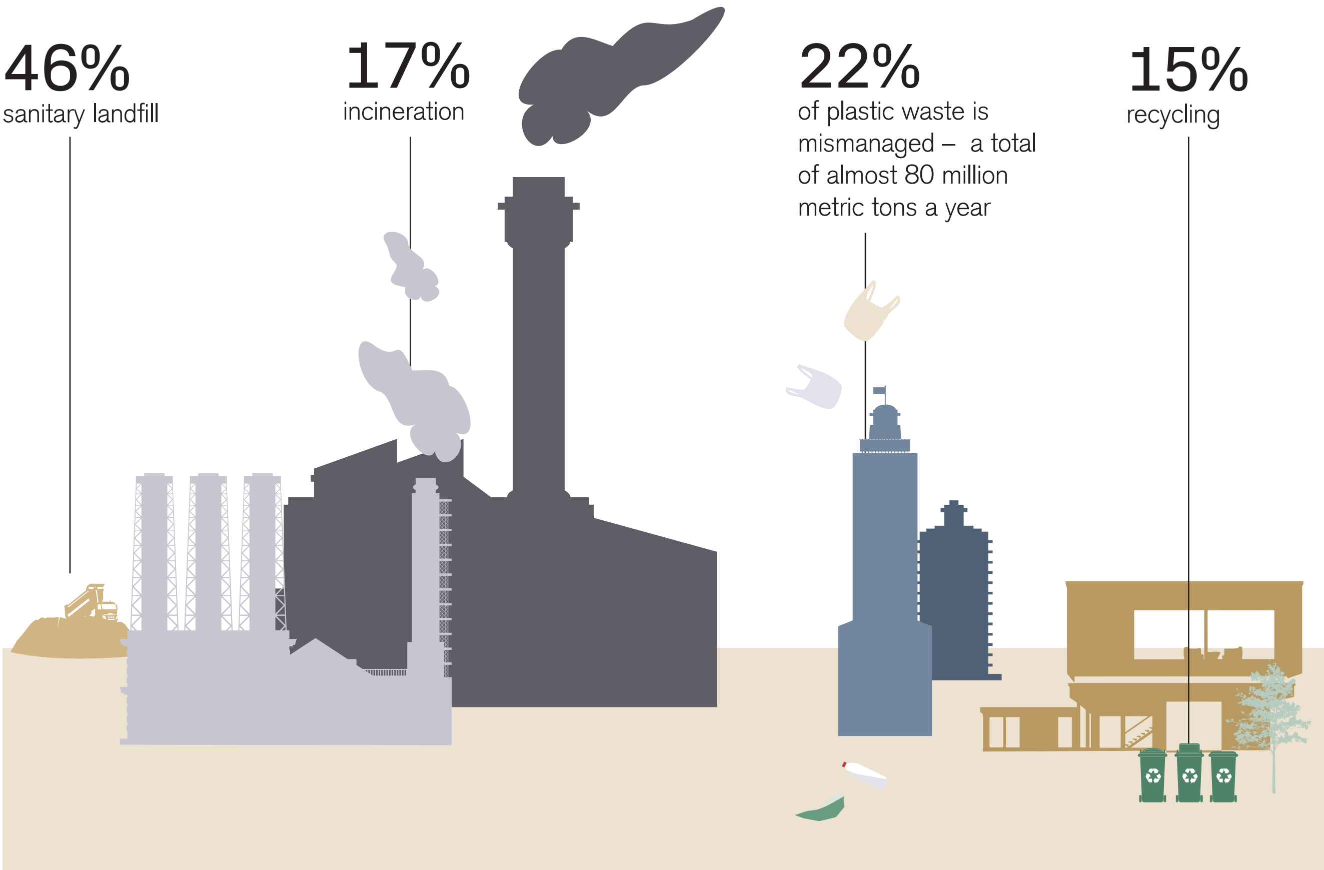
Mismanaged plastic waste – also termed plastic pollution – meets various fates, some of which cause limited, though still damaging, interaction with the environment. For example, three-quarters is captured in the inner part of dumpsites or burned in open uncontrolled fires. However, approximately 19 million metric tons is lost via leakage to terrestrial and aquatic environments. It is this volume of plastic – about 6% of annual plastic waste – that is arguably most damaging to the environment. When plastic leaks into the environment, it has many negative impacts on climate, biodiversity and social dimensions. The cost of plastic pollution is estimated to be at least USD 300 billion per annum and, according to certain estimates, as high as USD 1,500 (Landrigan et al., 2023).

Climate impacts

It has been estimated that over 90% of plastics are produced using virgin fossil fuel-based feedstock (OECD, 2022c). Estimating the total greenhouse gas emissions linked to the plastics industry is complex. Combining our baseline plastic-usage estimates with carbon-intensity figures from the OECD results in a 2060 annual plastic lifecycle emission forecast of approximately 3.1 gigatons of CO_2 equivalent. This quantum of emissions is the same as what would be produced by approximately 1,500 coal-fired power plants operating at full capacity each year, using an average capacity of 500 MW.[1] By comparison, there are over 450 coal-fired power plants in India (Global Energy Monitor, 2023). This illustrates the scale of plastics' carbon footprint.

1. According to the US Energy Information Administration, an average 500 MW coal-fired power plant in the US emitted 1,042 pounds of CO_2 per megawatt-hour in 2019. This translates to approximately 0.472 tons of CO2 per megawatt-hour. At full capacity, for 8,760 hours per year, the total CO_2 emissions for a coal-fired power plant would be 500 MW x 0.472 tons of CO_2/MWh x 8,760 hours/year = 2,075,200 tons of CO_2 per year.

Each year more than 350 million metric tons of plastic becomes plastic waste



Source: OECD, Credit Suisse

Biodiversity impacts

The effects on biodiversity can stem from the toxicity of plastics. These chemicals can leach into the environment, polluting waterways and soils, and posing a threat to both aquatic and terrestrial organisms. Microplastics interact with, and impact the health of soil-dwelling invertebrates, terrestrial fungi and plant pollinators, thus disrupting essential ecosystems. Microplastics can accumulate in soil and water, and alter microbial communities and nutrient availability. This can negatively impact processes such as nutrient cycling and carbon sequestration.

Plastics can also block waterways and choke marine life. The accumulation of plastics in natural environments can reduce the availability of food, shelter and nesting sites, ultimately leading to habitat destruction. Plastics can lead to species entanglement where many animals, including birds, marine mammals and fish, can mistake plastics for food and ingest them, leading to severe injuries, choking and death. For example, studies examining scarring on whales from the Gulf of Maine indicate that more than 80% of right whales and 50% of humpback whales have experienced entanglement in fishing gear (Knowlton et al., 2016; Robbins and Mattila, 2004).

Social impacts

Research has indicated that the levels of harmful plastic pollution may have exceeded safe limits for humanity (Persson et al., 2022). Plastic pollution threatens human health when it enters food and water supply. A study supported by the University of Newcastle estimates that an average person could consume as much as five grams of plastics per week, the equivalent of eating a credit card (Dalberg Advisors, De Wit and Bigaud, 2019).

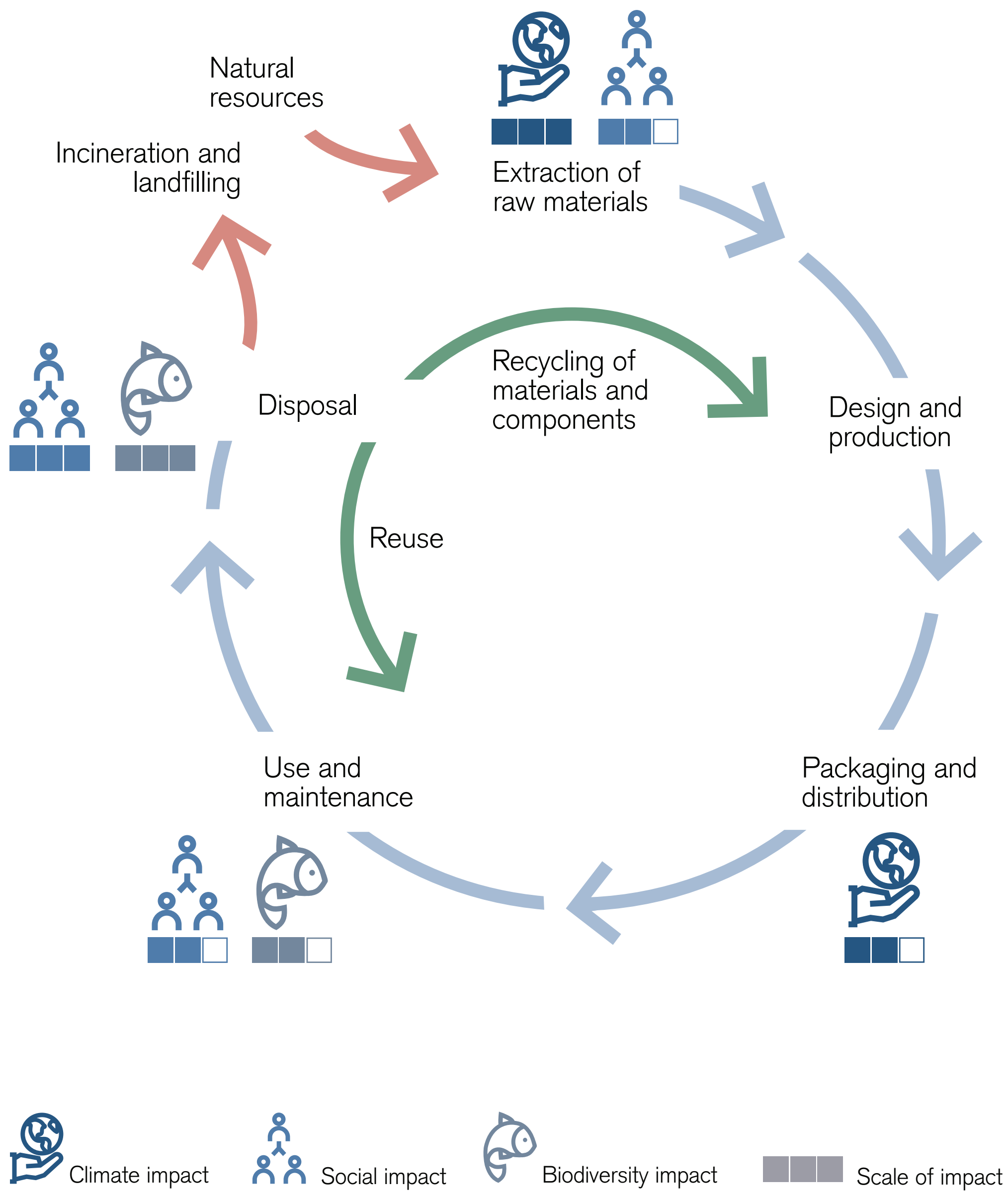
Air pollution from the open burning of plastics further harms human health. Exposure to plastics can affect fertility, hormonal, metabolic and neurological activity, with pregnant women and young children being particularly vulnerable. Plastic pollution is also associated with an increased risk of premature births, neurodevelopmental disorders, male reproductive birth defects, infertility, obesity, cardiovascular disease, renal disease and cancers (Azoulay et al., 2019).

Plastic poses a severe threat to human rights worldwide, particularly for vulnerable and marginalized communities. The extraction of raw materials and plastic production often lead to deforestation and displacement of indigenous peoples as well as the contamination of water and air, causing harm and health problems for local communities. Finally, the impact of marine plastic pollution disproportionately affects island nations and their right to a healthy environment (UN Human Rights, 2022).

Awareness about plastic

Awareness about plastic's harmful consequences has been growing since the 1960s, with policy responses accelerating since the turn of the millennium. According to the United Nations Environment Programme (UNEP), approximately two-thirds of countries have adopted some form of legislation to regulate plastic bags; and around a third have mandates for extended producer responsibility for single-use plastics, including deposit refunds, product take-back and recycling targets.

Potential circularity of plastic life cycle



Source: UNEP, Credit Suisse

Despite the policy action, plastic usage and plastic waste have continued to increase, with the latter up 130% since 2000. Mismanaged plastic volumes have also significantly increased, up almost 100% since 2000 and climbing from approximately 40 million metric tons per year to the current 80 million metric tons (OECD, 2022a).

> “
> ## The cost of plastic pollution is estimated to be at least USD 300 billion per annum

At a global level, in March 2022, the United Nations Environment Assembly adopted a landmark resolution and initiated negotiations for a global plastics treaty to end plastic pollution. In what could be the most significant sustainability-focused multilateral proposal since the Paris Agreement in 2015, the resolution establishes an Intergovernmental Negotiating Committee (INC) tasked with preparing a legally binding treaty by 2024. The first Intergovernmental Negotiation Committee meeting took place in December 2022 in Uruguay, with 145 countries backing calls for common global rules and standards. The second negotiation meeting takes place in Paris, France from 29 May to 2 June, with a draft treaty seeking to be prepared before a third meeting scheduled for Kenya in November 2023.

Plastic: A selected timeline

1862: Parkesine
Alexander Parkes patents the first plastic products in 1862. Parkesine is made from cellulose – a natural product – and is moldable when heated, and keeps its shape when cooled.

1907: Bakelite
Leo Baekeland patents Bakelite – the first totally synthetic plastic. It is heat resistant and its properties make it an effective electrical insulator.

1925: Terminology
The term "plastic" is introduced. Its roots are from the Latin word "plasticus" (to mold) and from the Greek words "plastikos" and "plassein" (to form).

1935: Polyethylene
Michael Perrin creates a practical method to produce polyethylene. It becomes the most common plastic produced in the world. High density polyethylene is used to make milk bottles. Low density polyethylene is used to make plastic bags and squeezable bottles.

1946: Tupperware
Earl Tupper purifies polyethylene slag, a waste product, and molds it into lightweight unbreakable kitchen items known as Tupperware.

1960s: Pollution
The plastic bag industry funds "Keep America Beautiful" advertisements that shift the responsibility for pollution prevention from producers to consumers.

1960s/1970s: Microplastics
Scientific papers describe small plastic fragments in birds and in plankton net samples. Since then, microplastics have also been found in the air, tap water, sea salt and the fish that humans eat.

1970s: Medical applications
Flexible plastic intravenous bags are used commercially. The bag allows for closed transfusions and reduces the risk of contamination. Single-use plastic items replace many multi-use glass and metal items once used for medical tasks.

1989: Basel Convention
The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal is adopted. Currently, there are 188 parties to the Convention; it does not include the United States.

1993: Recycled clothing
Clothing company Patagonia begins to use recycled bottles to create its fleece clothing. Plastic bottles are cleaned, melted, stretched and woven into fabric.

1997: The Great Pacific Garbage Patch
Yachtsman Charles Moore sails through a huge tract of floating plastic debris in the Pacific Ocean. Oceanographer Curtis Ebbesmeyer names it "The Great Pacific Garbage Patch."

2002: Plastic bags
Plastic bags are deemed to be blocking the drainage systems in Bangladesh, causing major flooding. As a result, Bangladesh becomes the first country to ban single-use plastic bags.

2014: Microbeads
The Netherlands becomes the first country to ban microbeads in cosmetics and wash-off cleaning products.

2022: Antarctica
New Zealand researchers discover microplastics present in Antarctic snow. Microplastics have now been found in every continent on Earth.

2022: Global action
The United Nations Environment Assembly adopts a landmark resolution and initiates negotiations for a global plastics treaty to end plastic pollution.

Source: Science Learning Hub, GESAMP, Credit Suisse

panaramka, Getty Images

Introducing the Plastic Kaya Identity

Key points:

- The Kaya Identity is a cornerstone of carbon emission and net zero forecasting. We introduce a parallel concept – the Plastic Kaya Identity – to understand and forecast plastic usage and pollution.
- We find that the plastic usage intensity of global GDP has increased by almost 5,000% between 1960 and 2020 and that annual mismanaged plastic – or plastic pollution – has increased from approximately 21 million metric tons in 1990 to approximately 80 million metric tons in 2020.
- Globally, 22% of plastic waste is mismanaged and becomes plastic pollution. This is greater than the percentage of plastic waste that is recycled at just 15%.

The CO_2 Kaya Identity

The Kaya Identity was developed by Japanese economist Yoichi Kaya in the early 1990s and has since become a key mechanism for understanding carbon emissions as a function of economic, demographic and power generation factors (Kaya and Yokoburi,1997).

The Kaya Identity is a mathematical identity that expresses total carbon dioxide (CO_2) emissions levels as a product of four parameters. It multiplies human population by gross domestic product (GDP) per capita, by the energy intensity of GDP, and by the carbon emission intensity of energy. The Kaya Identity appears regularly in climate literature and underpins the future emission scenarios that are published by the Intergovernmental Panel on Climate Change.

Formulaically, the Kaya Identity can be expressed as:

$$F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E}$$

Where:
F is global CO_2 emissions from human sources
P is global population
G is global GDP
E is global energy consumption

And:
G/P is GDP per capita
E/G is the energy intensity of GDP
F/E is the emission intensity of energy

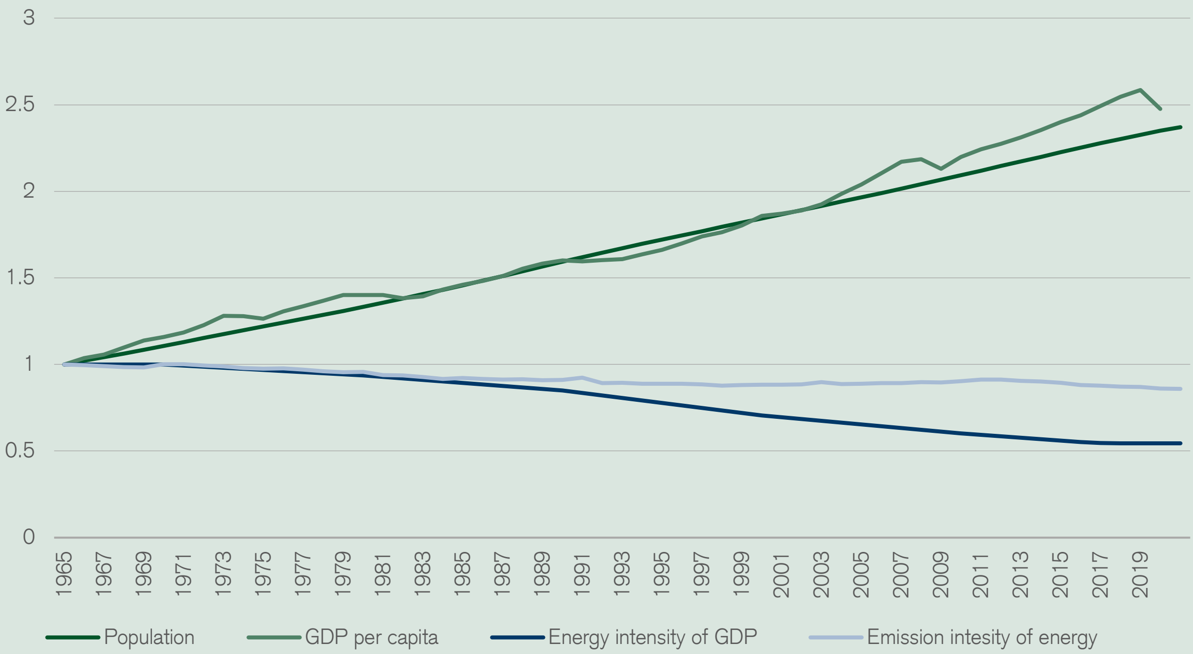
The Kaya Identity can be used to visually express the challenges in abating carbon emissions. When visualizing time series of each of the four parameters it is revealed that rising populations and standards of living (as expressed by GDP per capita) create significant upward pressure on global carbon emissions (see **Figure 1**).

The Plastic Kaya Identity

Inspired by the Kaya Identity, we can break down both plastic use and plastic pollution into a similar identity. In the case of plastic pollution, we retain the first two terms on the right-hand side of the Kaya Identity – i.e. population and GDP per capita – and replace the energy intensity of GDP with its plastic waste equivalent. We also replace the carbon intensity of energy with the ratio of mismanaged plastic waste to total plastic waste.

Figure 1: The Kaya Identity – drivers of CO_2 emissions

Parameter time series, rebased to 1 as of 1965



Source: BP Statistical Review of World Energy, Global Carbon Project, OECD, Our World in Data, UN, World Bank, Credit Suisse; last data point: 2020

Formulaically, we express mismanaged plastic waste – or plastic pollution – as follows.

$$M = P \times \frac{G}{P} \times \frac{W}{G} \times \frac{M}{W}$$

Where:
M is mismanaged plastic waste (plastic pollution)
P is global population
G is global GDP
W is plastic waste

And:
G/P is GDP per capita
W/G is the plastic waste intensity of GDP
M/W is mismanaged plastic waste as a proportion of total plastic waste

We term this the Plastic Kaya Identity and we perform the Plastic Kaya Identity on data from the OECD Plastics Outlook Database, which consolidates and extends multiple academic studies to provide estimated annual figures relating to plastic usage dating back to 1950, with the granular time series for plastic pollution dating from 1990.

We supplement this dataset with population figures from the United Nations (2022) and GDP metrics from the World Bank (2023) (using its constant 2015 US dollar variant, adjusted for inflation but not purchasing power parity (PPP) between countries) to ensure an annual time series dating back to 1960.

The Plastic Usage Kaya Identity

Over the entire time horizon of study from 1960 to 2020, the data indicate that plastic usage has dramatically outstripped both GDP and population growth. Plastic usage has increased by almost 5,000%, while real GDP has grown by approximately 650% and population has more than doubled, increasing by approximately 160% (**Figure 2**).

We perform a variant of the Plastic Kaya Identity to understand the drivers of plastic usage. The key difference between the Plastic Kaya Identity and the Plastic Usage Kaya Identity is that, in the latter, the left-hand term is plastic usage, not plastic pollution. This enables us to understand the demographic and economic parameters of plastic usage. This is formulaically expressed as:

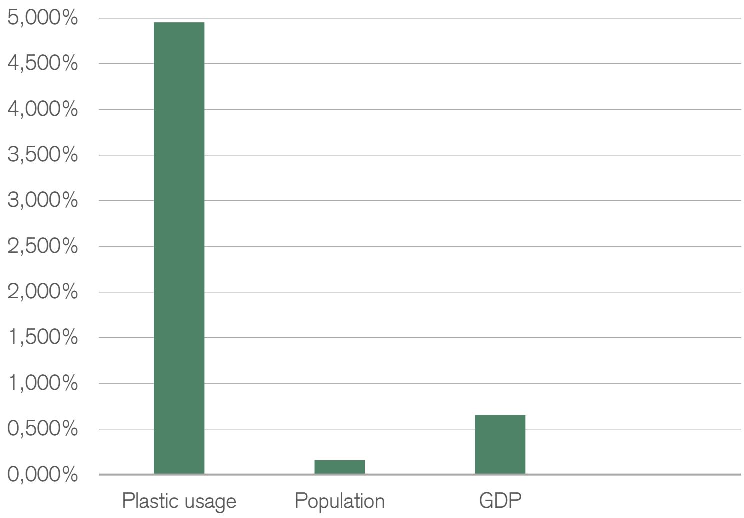
$$U = P \times \frac{G}{P} \times \frac{U}{G}$$

Where:
U is plastic usage
P is global population
G is global GDP

And:
G/P is GDP per capita
U/G is the plastic usage intensity of GDP

Figure 2: Plastic usage has outstripped both GDP and population growth

Absolute change 1960–2020, in %



Source: OECD, UN, World Bank, Credit Suisse

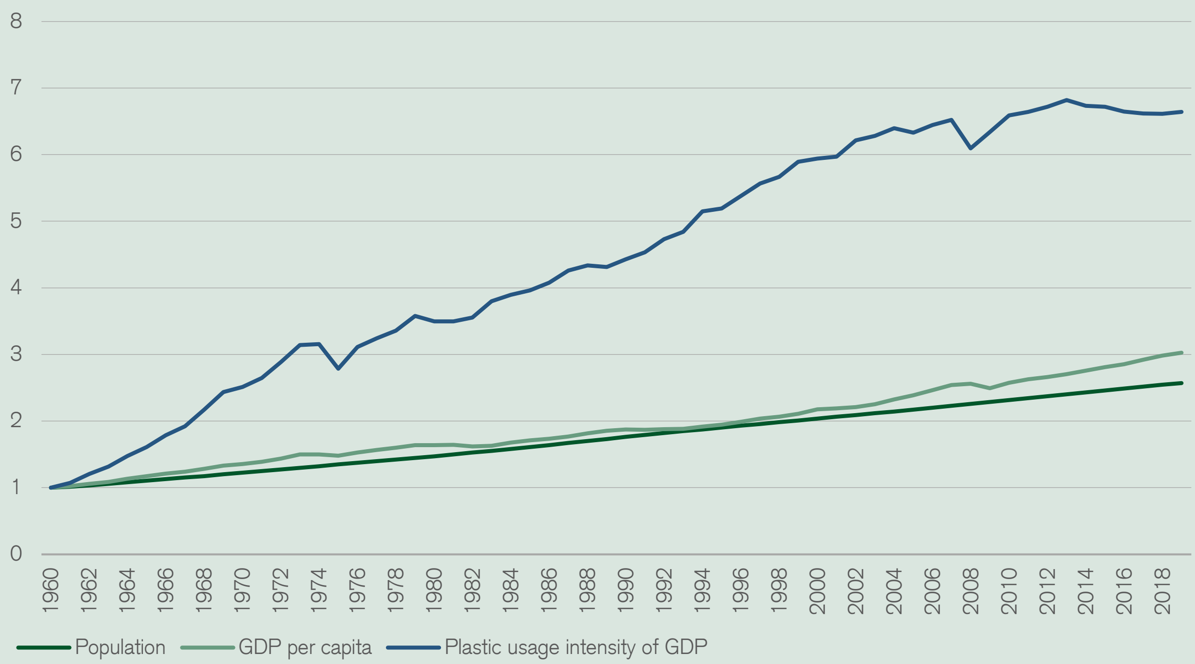
The Plastic Usage Kaya Identity demonstrates that the plastic intensity of GDP increased dramatically from 1960 to 2000. For every dollar of GDP added to the global economy, the data suggest that more and more plastic was required, making the global economy heavily plastic reliant.

The graphical representation of the Plastic Usage Kaya Identity is in stark contrast to the original CO_2 Kaya Identity. In the original Kaya Identity, the dominant mathematical parameters are GDP per capita and population growth, while the energy intensity of GDP declined. In the Plastic Usage Kaya Identity, the plastic intensity of GDP is more significant than both GDP per capita and population growth.

The graphical representation of the Plastic Usage Kaya Identity also reveals a stabilization in the plastic usage intensity of GDP starting around the year 2000. This coincides with greater public awareness of the impact of plastic on climate, biodiversity and social variables (**Figure 3**).

Figure 3: The Plastic Usage Kaya Identity – drivers of plastic usage

Parameter time series, rebased to 1 as of 1960



Source: OECD, UN, World Bank, Credit Suisse; last data point: 2019

The Plastic Kaya Identity

From 1990 onward, owing to the OECD's granular dataset, we can introduce our final mathematical term, i.e. mismanaged plastic waste as a proportion of total plastic waste. In doing so, we shift our focus from plastic usage to plastic waste.

In absolute terms, annual mismanaged plastic – or plastic pollution – has increased from approximately 21 million metric tons in 1990 to 80 million metric tons in 2020 (OECD, 2022a).

Breaking down absolute plastic pollution and expressing it as a Plastic Kaya Identity yields the time series shown in **Figure 4**.

The data reveal that, unlike the period from 1960 to 1990, the plastic waste intensity of GDP is no longer the outsized driver. In addition, much like the original CO_2 Kaya Identity, GDP per capita and population growth are important contributors to the increase in plastic pollution.

Moreover, it is evident that, over the last decade, mismanaged plastic as a proportion of total plastic waste has declined – in other words, we have collectively become better at appropriate plastic waste disposal.

The Plastic Kaya Identity poses critical questions for the future of plastic pollution. Can we reduce the plastic waste intensity of GDP (mitigation) and/or achieve better plastic waste management practices (adaptation)? Furthermore, can these actions offset the seemingly inevitable increase in plastic usage demand related to population growth and rising standards of living?

Before we explore projections, policy options and their impact, we will first examine the geographic drivers behind our data by splitting several plastic usage and plastic pollution metrics into OECD and non-OECD components.

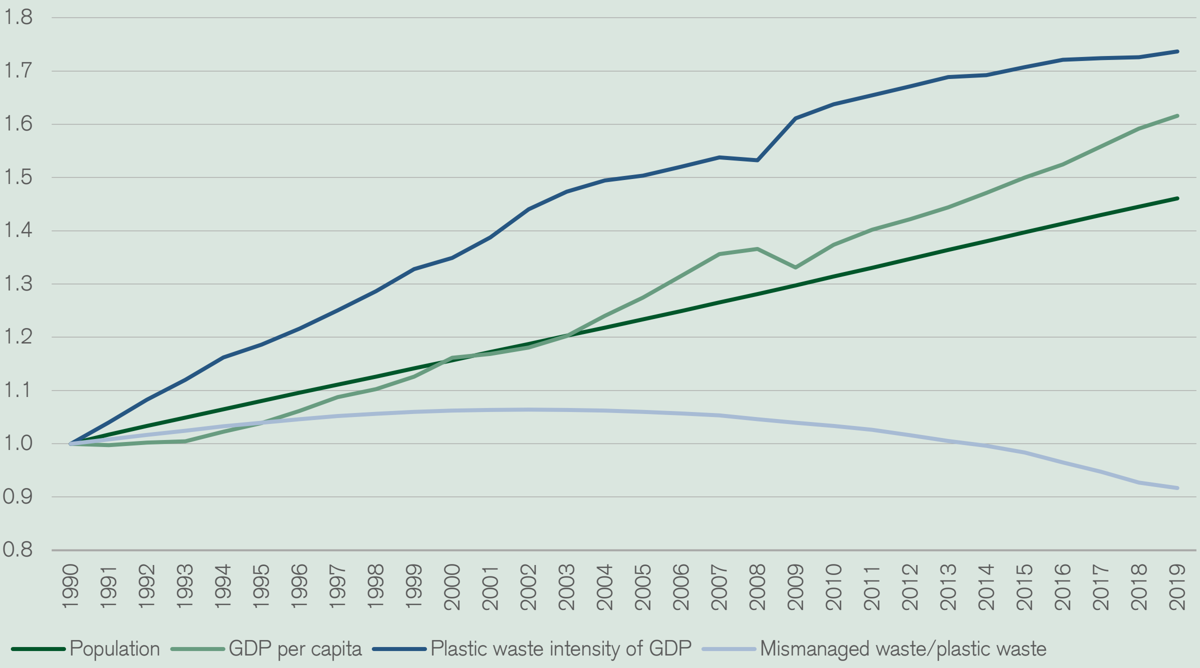
Regional drivers of plastic usage

The OECD Global Plastics Outlook Database finds that OECD countries and non-OECD countries use approximately the same amount of plastic per year. In absolute terms, OECD countries utilize approximately 207 million metric tons of plastic compared to non-OECD countries, which use approximately 243 million metric tons (OECD, 2022a; see **Figure 5**).

However, this symmetry dissolves when the data are viewed on a per-capita basis, with the global average of 57 kilograms per person per year masking the OECD's huge 155 kilogram figure and the non-OECD's more moderate 40 kilograms (**Figure 6**).

Figure 4: The Plastic Kaya Identity – drivers of plastic pollution

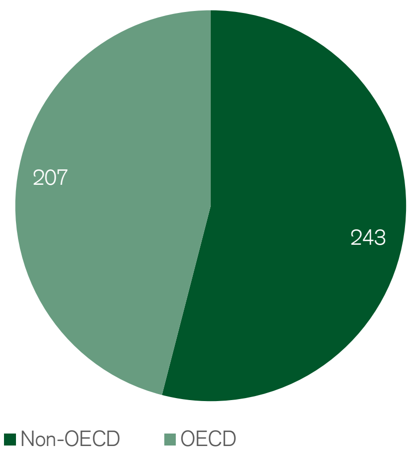
Parameter time series, rebased to 1 as of 1990



Source: OECD, UN, World Bank, Credit Suisse; last data point: 2019

Figure 5: OECD and non-OECD countries use similar absolute amounts of plastic

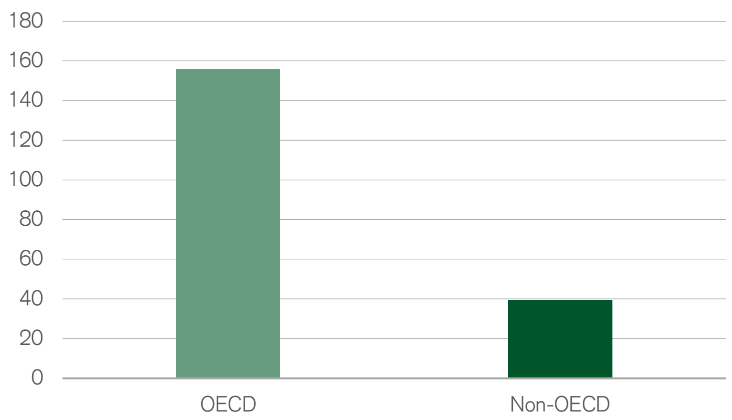
Absolute plastic usage, in millions of metric tons per annum, 2019



Source: OECD, Credit Suisse

Figure 6: OECD and non-OECD countries use vastly different amounts of plastic per capita

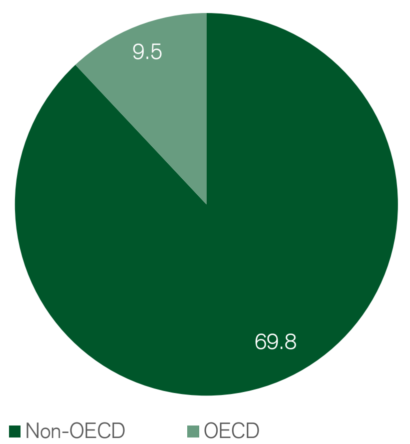
Per capita usage, in kilograms per annum, 2019



Source: OECD, Credit Suisse

Figure 7: Non-OECD countries account for the vast majority of mismanaged plastic waste

Mismanaged plastic waste, in millions of metric tons per annum, 2019



Source: OECD, Credit Suisse

Although plastic usage per capita is considerably different between the OECD and non-OECD, the plastic usage intensity of GDP is almost identical for both groupings. Thus, while non-OECD population and economic growth may drive absolute plastic usage higher, this suggests that the global plastic usage intensity of global GDP may have peaked.

> “Annual mismanaged plastic, or plastic pollution, has increased from approximately 21 million metric tons in 1990 to 80 million metric tons in 2020

Regional drivers of plastic pollution

While absolute plastic usage is broadly split evenly between the OECD and non-OECD countries, plastic pollution is not. Of the approximately 80 million metric tons of mismanaged plastic, almost 70 million metric tons (88%) originate from non-OECD counties (OECD, 2022a, see **Figure 7**).

If we dig deeper into the origins of this mismanaged plastic waste, we find that, at a global level, 22% of plastic waste is mismanaged (this is greater than the percentage recycled at just 15%). However, there is significant regional disparity beneath the headline figures, whereby OECD countries mismanage approximately 6% of their plastic waste, compared to the non-OECD figure of 37%. Intriguingly, differences in recycling practices are not behind the disparity in mismanaged plastic waste, with the OECD and non-OECD blocks exhibiting similar recycling percentages (**Figure 8**). Despite the disparity, both OECD and non-OECD regions have improved their sanitary plastic disposal practices in recent years. In the OECD countries, mismanaged plastic as a proportion of total plastic waste has declined by almost 60% since 1990, while the ratio has decreased by almost 30% in non-OECD countries.

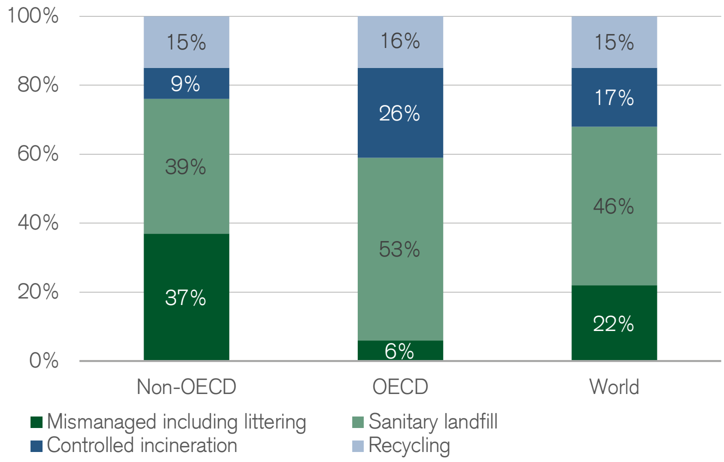
Taken individually, these are material achievements. However, despite both groupings decreasing mismanaged plastic waste as a proportion of total plastic usage, the global ratio has not decreased as significantly (**Figure 9**).

This statistical quirk is a result of non-OECD countries increasing their absolute plastic usage at a faster rate than OECD countries. As a result, the "mix" of the two mismanagement rates is increasingly weighted on the less favorable non-OECD figure.

> Both OECD and non-OECD regions have improved their sanitary plastic disposal practices in recent years

Figure 8: Non-OECD countries mismanage a greater percentage of plastic waste than OECD countries

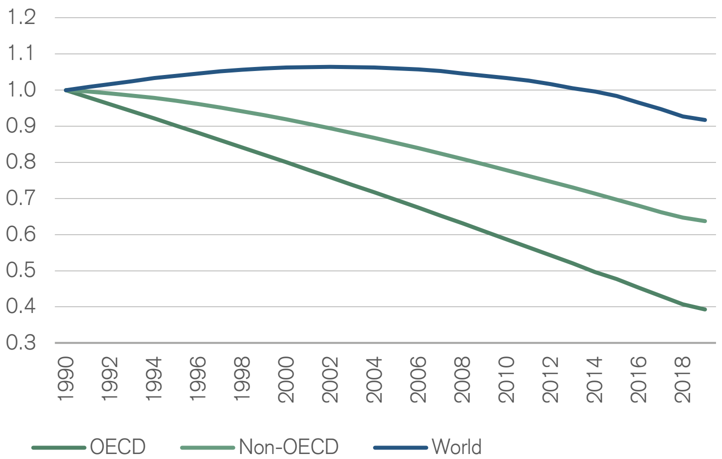
Plastic waste end-of-life fate, in %



Source: OECD, Credit Suisse

Figure 9: The percentage of mismanaged plastic waste has declined slowly

Mismanaged plastic waste as a proportion of plastic waste, time series rebased to 1 as of 1990



Source: OECD, Credit Suisse; last data point: 2019


Philip Thurston, Getty Images

Forecasting the future

A framework for forecasting

Our forecasting framework extends out to 2060 and is based on the previously described Plastic Kaya Identity.

We use long-term population forecasts from the United Nations and long-term real GDP forecasts from the OECD's long-term GDP forecast database. The latter is arguably conservative in nature as the dataset expects real GDP year-over-year growth to slow to 2.5% per annum by 2030 and to just 1.5% per annum by 2060 (Braconier, Nicoletti and Westmore, 2014, see **Figure 1**). It should be noted that, given the importance of GDP in our Plastic Kaya Identity forecasting framework, the total amount of plastic pollution is sensitive to GDP forecasts.

The remaining variables to forecast plastic pollution are:
1. The plastic waste intensity of GDP, i.e. how much plastic is needed to produce a unit of GDP.
2. Mismanaged plastic waste as a proportion of total plastic waste, i.e. how much plastic waste becomes plastic pollution.

As per our climate-net-zero-inspired approach, these two variables are impacted by mitigation and adaptation actions. Mitigation actions reduce plastic usage (e.g. through taxation) to suppress plastic demand. Such actions decrease the plastic waste intensity of GDP. Adaptation strategies accept the need for plastic in our economy, but seek to reduce the mismanagement of plastic waste (e.g. through improved recycling practices). These decrease mismanaged plastic waste as a proportion of total plastic waste.

For this analysis, we present three scenarios that draw on work from the OECD.

First, a baseline scenario where the plastic waste intensity of GDP and mismanaged plastic waste as a proportion of total plastic waste are only affected by current trends, without any additional policy actions.

Key points:

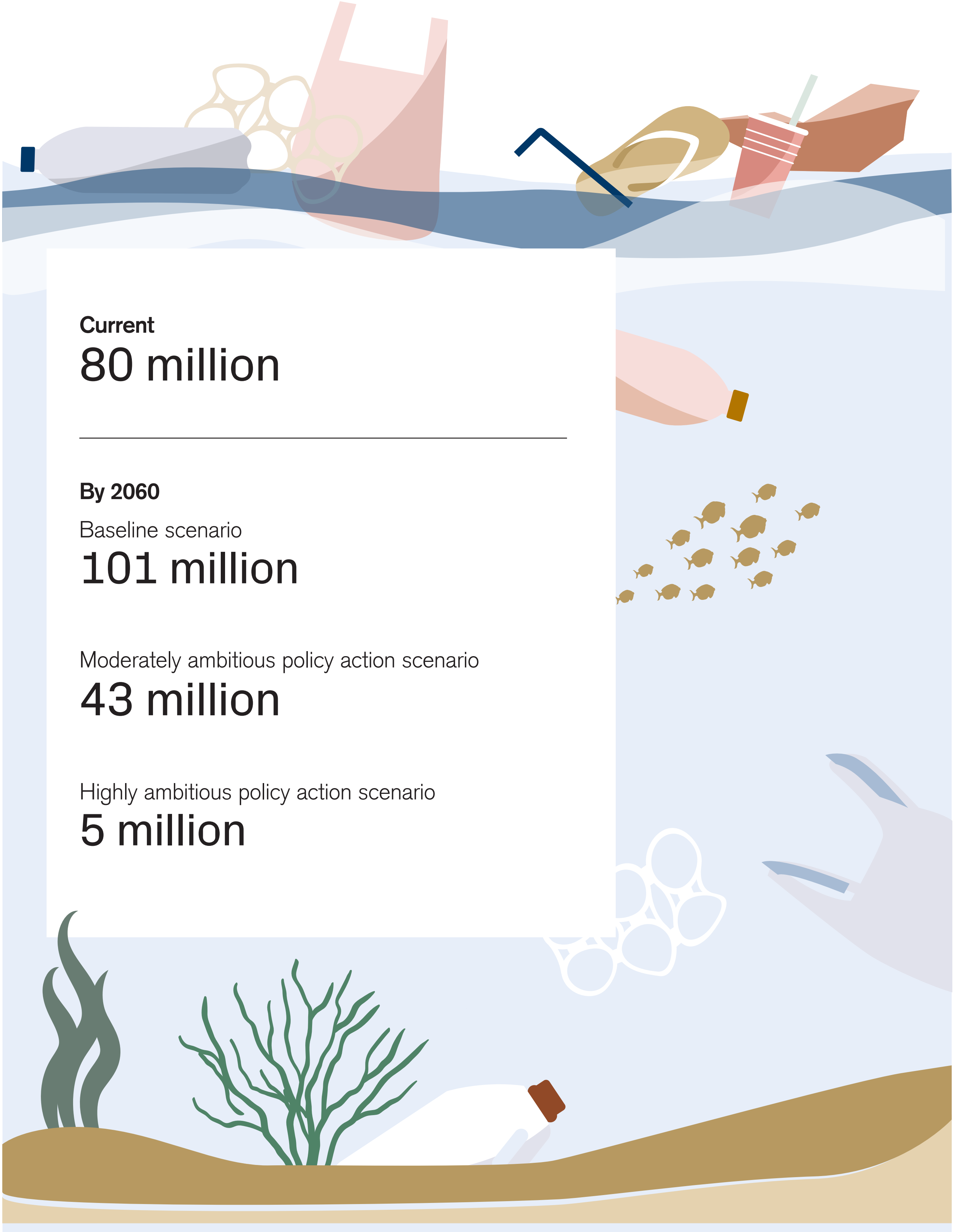
- Our forecasting framework extends out to 2060 and is based on our Plastic Kaya Identity. In the baseline scenario, we extend current trends and assume no additional policy action.
- Changing economic activities decrease the plastic waste intensity of GDP by 15% and the existing trajectory for waste management reduces mismanaged plastic waste as a proportion of total plastic waste from 22% to 15%. However, these factors are more than offset by population and economic growth.
- This results in annual mismanaged plastic waste increasing from approximately 80 million metric tons to just over 100 million metric tons in 2060.

Second, a moderately ambitious scenario that includes mitigating actions such as a regional plastic tax to constrain demand and adaptation actions to close leakage pathways, e.g. public investment in mixed waste collection and sanitary landfills.

Third, a highly ambitious scenario that envisages mitigating actions such as global plastic taxation and a global extended producer responsibility strategy to increase product durability and extend lifecycles across packaging, electronics and motor vehicles. Adaptation elements include significant investment in recycling, mixed waste collection and litter collection.

In all the scenarios, we maintain the same population and GDP per capita forecasts. This is a partial simplification as legislative action does come with a financial cost – namely a slight reduction in global GDP. As a further simplification, the forecast 2060 outcomes are assumed to occur in a linear fashion in the intervening years and thus do not account for the timing of policy actions and any resulting changes in plastic pollution volume.

Forecast annual mismanaged plastic waste, in metric tons



Current

80 million

By 2060

Baseline scenario

101 million

Moderately ambitious policy action scenario

43 million

Highly ambitious policy action scenario

5 million

Source: OECD, Credit Suisse

Figure 1: Global real GDP growth is expected to slow

Forecast real GDP growth, year over year, in %

Source: OECD, Credit Suisse

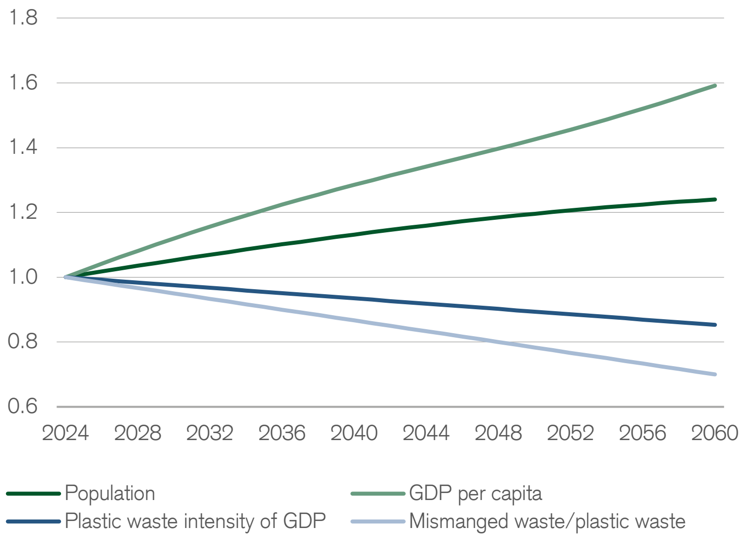
Figure 2: Plastic waste is expected to increase significantly in the coming decades

Absolute plastic waste and mismanaged plastic waste, in millions of metric tons p.a.

Source: OECD, Credit Suisse

Figure 3: The Plastic Kaya Identity – drivers of forecast plastic pollution

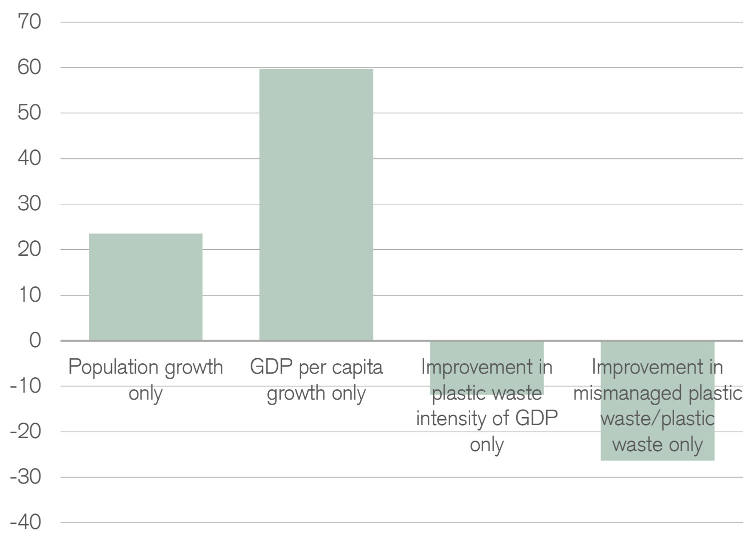
Parameter time series, rebased to 1 as of 2024



Source: OECD, UN, World Bank, Credit Suisse

Figure 4: Improving standards of living will likely materially contribute to mismanaged plastic waste

Hypothetical impact per parameter, holding all other terms constant, in million tons



Source: OECD, UN, World Bank, Credit Suisse

Baseline scenario

In this scenario, which could be considered a bear case, we extend the current policies and consider the evolution in global economic activity by sector and geography. This results in the plastic waste intensity of GDP declining by 15% in 2060, compared to 2019 levels. The existing trajectory for improving waste management also reduces mismanaged plastic waste as a proportion of total plastic waste from the current 22% to 15% by 2060.

In the baseline scenario, the amount of annual plastic waste almost doubles from approximately 350 million metric tons to 670 million metric tons. However, annual mismanaged plastic waste increases by a far smaller proportion from approximately 80 million metric tons to just over 100 million metric tons in 2060 (**Figure 2**).

> In the baseline scenario, the amount of annual plastic waste almost doubles from approximately 350 million metric tons to 670 million metric tons

We can visualize the drivers of this evolution via the Plastic Kaya Identity, which reveals, under this model, that GDP per capita is the most significant parameter in the projected increase in plastic pollution (**Figure 3**). We can also visualize the data through a hypothetical exercise, which adjusts only one term in the Plastic Kaya Identity at a time, holding the rest constant at the 2019 baseline. This exercise does not account for interaction effects between the terms in the Plastic Kaya Identity, but does provide a helpful and rough guide to the relative impact of each driver on plastic pollution (**Figure 4**).

Moderately and highly ambitious scenarios

The precise policy details of the moderately and highly ambitious scenarios provided by the OECD are beyond the scope of this paper and can be read in detail in the OECD's "Global Plastics Outlook: Policy Scenarios to 2060." (OECD, 2022b) Inputting the moderately ambitious scenario into our models results in a 30% decrease by 2060 in the plastic waste intensity of GDP, compared to 2019 levels. It also reduces mismanaged plastic waste as a proportion of total plastic waste from 22% to less than 8% by 2060.

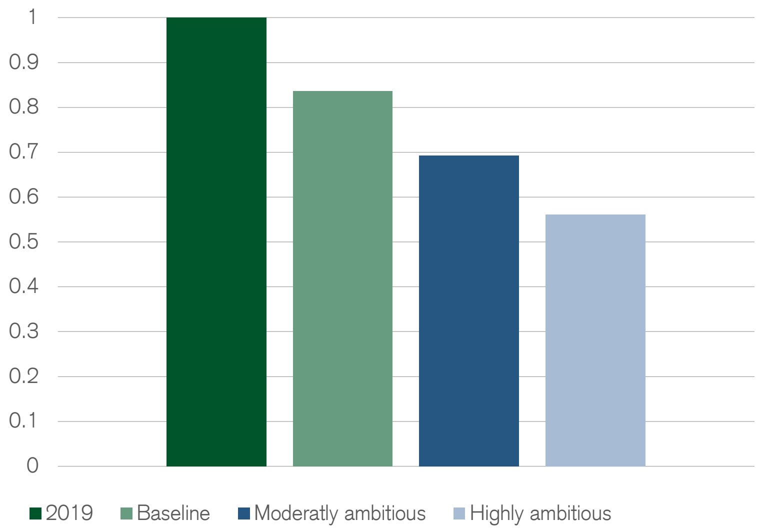
> The moderately ambitious scenario results in a 30% decrease in the plastic waste intensity of GDP by 2060 versus 2019 levels

In this scenario, taxation and other measures suppress the demand for plastic. However, the amount of annual plastic waste in 2060 increases from 2019 levels by more than 50% to approximately 550 million metric tons. However, thanks to improved plastic waste-disposal practices, the annual mismanaged plastic waste almost halves from approximately 80 million metric tons to just over 40 million metric tons in 2060.

The highly ambitious scenario results in a 45% decrease in the plastic waste intensity of GDP by 2060, compared to 2019 levels, and also reduces mismanaged plastic as a proportion of total plastic waste from 22% to approximately 1% by 2060.

Figure 5: The plastic waste intensity of GDP will likely decrease

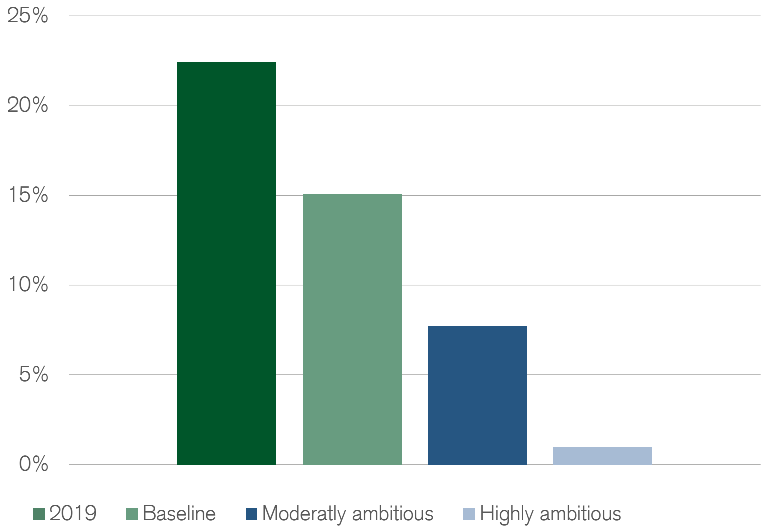
Forecast 2060 plastic waste intensity of GDP, rebased to 1 as of 2019



Source: OECD, UN, World Bank, Credit Suisse

Figure 6: The percentage of plastic waste which is mismanaged will likely decrease

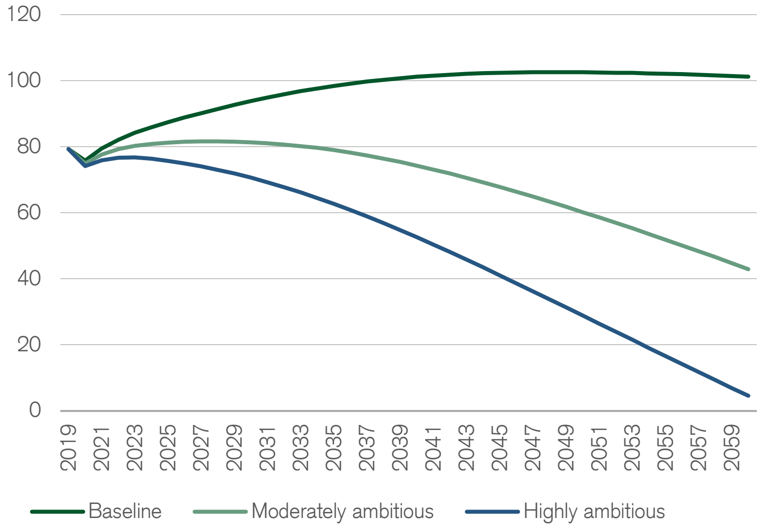
Forecast 2060 mismanaged plastic as a proportion of total plastic waste, rebased to 1 as of 2019



Source: OECD, Credit Suisse

Figure 7: The annual volume of mismanaged plastic waste will increase without further policy action

Parameter time series, rebased to 1 as of 2019



Source: OECD, UN, World Bank, Credit Suisse

Even in this scenario, the amount of annual plastic waste increases over the forecast period by approximately 30%, which is a firm indication that, even in the most ambitious policy scenarios, plastic still has a significant role to play in the global economy. However, owing to the dramatic reduction in mismanaged plastic as a proportion of total plastic waste, the amount of annual mismanaged plastic waste drops to almost zero by 2060 (see **Figures 5 and 6**).

We can visualize our scenarios as time series. Since our modelling includes a linear approximation, utilizing these charts to pinpoint "peak plastic waste" would be methodologically erroneous. Nevertheless, the charts give an indication of what is needed to "bend the curve" of plastic pollution (**Figure 7**).

Figure 8: The quantum of mismanaged plastic waste is sensitive to variation in parameters

Sensitivity analysis derived from the Plastic Kaya Identity; 2060 mismanaged plastic waste, in millions of metric tons

Change in the plastic waste intensity of GDP compared to 2019	Mismanaged plastic as a percent of plastic waste: 1%	5%	10%	15%	22%
0%	8	40	80	120	181
-15%	7	34	68	102	154
-25%	6	30	60	90	135
-35%	5	26	52	78	117
-45%	4	22	44	66	99

No improvement from 2019 parameters · Baseline scenario · Highly ambitious scenario

Dark border delineates 2060 annual figures that are higher / lower than 2019 annual figures

Source: OECD, UN, World Bank, Credit Suisse

It is also noteworthy that this visualization is a flow visualization. Even as annual plastic pollution figures decrease, the total stock of plastic pollution in the environment continues to increase. This is true in all the scenarios considered. Therefore, to reach net zero plastic pollution, merely reducing annual plastic pollution is insufficient. Plastic pollution removal or clean-up would also need to be part of the solution.

As a final exercise, we can use the Plastic Kaya Identity to perform a sensitivity analysis on a range of potential 2060 outcomes. Similar to our previous scenarios, we hold consistent the population and GDP per capita forecasts and then provide a range of figures for both the change in the plastic waste intensity of GDP and for the percentage of mismanaged plastic waste as a proportion of plastic waste (**Figure 8**).

> "
> **The highly ambitious scenario results in a 45% decrease in the plastic waste intensity of GDP by 2060**


Philip Thurston, Getty Images

Leakage pathways

Interaction with the environment

To establish credible adaptation and mitigation strategies for plastic pollution, we first need to further understand both the sources and resultant pathways for plastic to negatively interact with the environment.

First, we acknowledge its primary origination locations. Of the current 80 million metric tons of annual mismanaged plastic waste, almost 90% originates from non-OECD countries, with China and India contributing 22% and 11% to the global total, respectively (**Figure 1**).

Second, we note that not all mismanaged plastic waste directly interacts with terrestrial and aquatic environments. Around 34 million metric tons (43%) is estimated to be captured in the inner part of dumpsites, where degradation and interaction with the environment is close to zero. A further 26 million metric tons (33%) are burned in open uncontrolled fires. This is mainly done by households but can also be at dumpsites, where waste is burned deliberately to reduce volume or recover valuable metals. The remaining 19 million metric tons (24%) is lost via leakage to terrestrial and aquatic environments. This plastic pollution is joined by a further estimated three metric tons of leakage caused by sources such as transport-related microplastics and microplastic dust. It is this volume of plastic – about 6% of annual plastic waste – that is arguably most damaging to the environment (OECD, 2022a, see **Figure 2**).

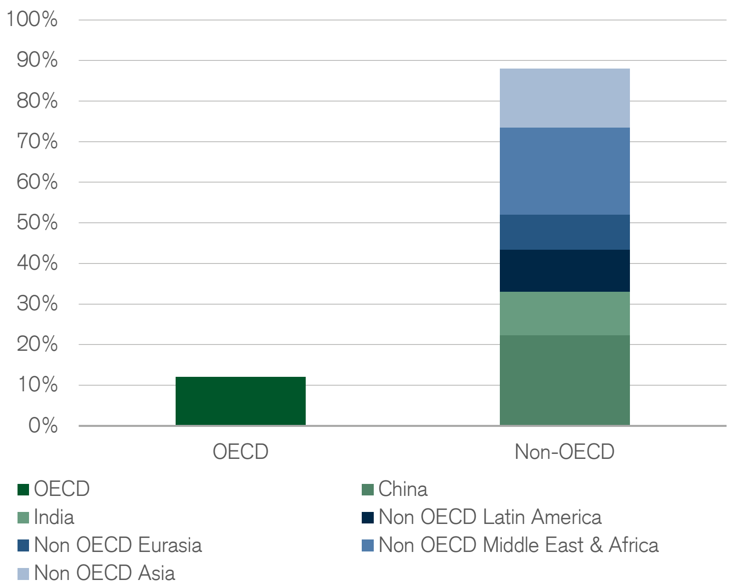
The leakage is predominantly made up of macroplastics – a group that encompasses recognizable items such as littered products and packaging. Microplastics – solid synthetic polymers smaller than five millimeters in diameter – represent a much smaller portion.

Key points:

- Not all mismanaged plastic waste directly interacts with terrestrial and aquatic environments. The majority is estimated to be captured in the inner part of dumpsites or burned in open uncontrolled fires.
- Approximately only a quarter of all mismanaged plastic waste is lost via leakage and meaningfully interacts with terrestrial and aquatic environments.
- We address the infamous (and subsequently disproved) 2016 statement from a report published by the Ellen MacArthur foundation that, by 2050, there would be more plastic metric tonnage than fish in the sea. With our revised dataset, we make an interesting – though less sensational claim – that, without additional policy action by 2060, there could be more plastic metric tonnage than whale biomass in the sea.

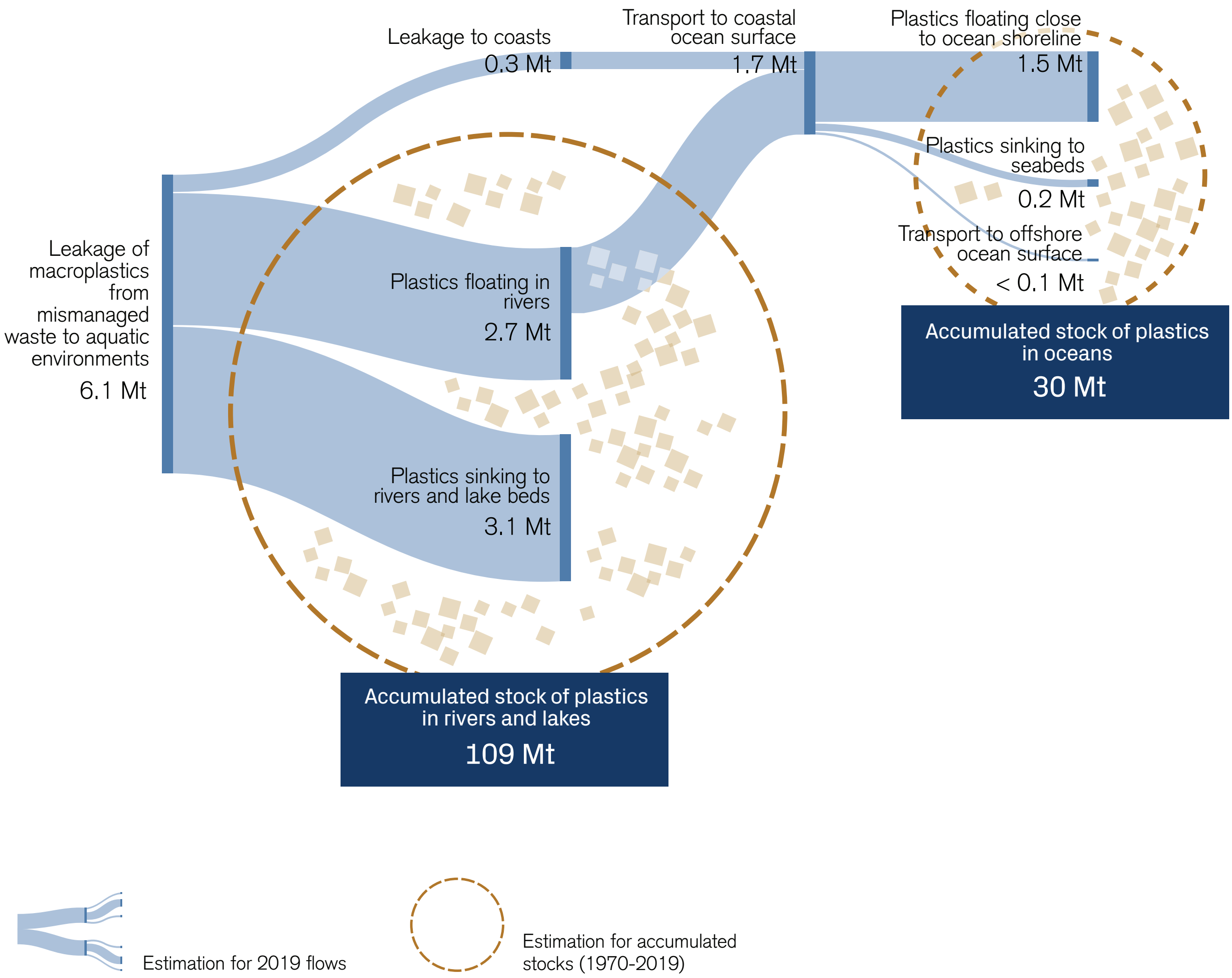
Figure 1: China and India account for a significant portion of mismanaged plastic waste

Percentage of mismanaged plastic waste, by country and region, 2019



Source: OECD, Credit Suisse

Rivers accumulate leaked plastic and carry them to the ocean



Source: OECD, Credit Suisse

There is still significant scientific uncertainty about these figures. Researchers at the University of Leeds believe that mismanaged plastic waste is some 30% lower than the 19 million metric tons suggested by the OECD, while researchers at the University of Denmark suggest a figure 30% higher, giving an uncertainty range of between 13 million metric tons and 25 million metric tons (OECD, 2022c).

Aquatic environments

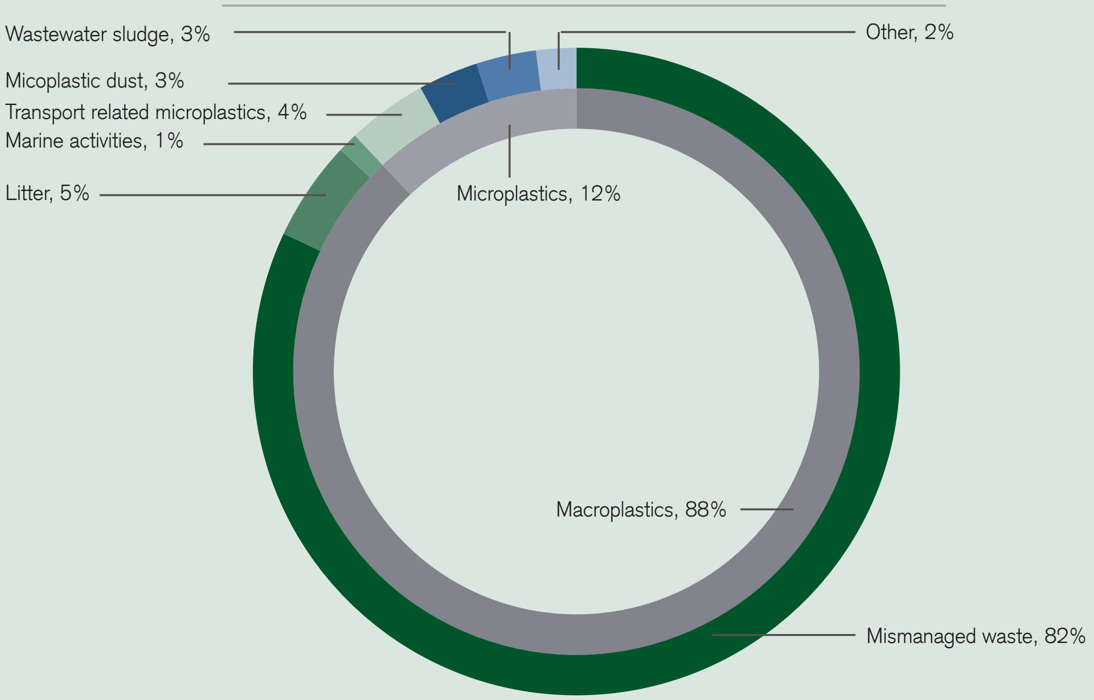
Some years ago, a report published by the Ellen MacArthur Foundation suggested that, by 2050, there would be more plastic tonnage than fish biomass in the sea (Ellen MacArthur Foundation, World Economic Forum and McKinsey & Company, 2016). This understandably generated headlines around the world. The underlying estimates used in the report have since come under criticism as the estimate of plastic stock in the ocean as well as its increase over time were based on a report by the Ocean Conservancy (Ocean Conservancy and McKinsey & Company, 2015), which was subsequently publicly withdrawn due to material inaccuracies.[1] Ocean Conservancy estimated an ocean plastic stock of approximately 150 million metric tons for 2015, without detailing the calculations.

The Ellen MacArthur report added annual plastic waste leakage estimates, derived from a 2015 study (Jambeck et al., 2015), which assumed estimated plastic waste generated in coastal regions flowed into the ocean, disregarding prevention measures. Furthermore, the Ellen MacArthur report utilized a low estimate of fish tonnage.

1. Ocean Conservancy withdrew the report and issued a public Statement of Accountability ("Trash Free Seas: Stemming the Tide Statement of Accountability – Ocean Conservancy").

Figure 2: Global plastic leakage is predominantly macroplastics from mismanaged plastic waste

2019 plastic leakage into the environment, in %



Source: OECD, Credit Suisse

We aim to provide an updated statement on the aquatic environment and find a more probable statement that, by 2060, there could be more plastic tonnage than whale biomass in the sea.

Measuring ocean plastic pollution

We start our analysis by utilizing the OECD estimates forecasting that approximately six million metric tons of plastic leak into aquatic environments per annum. This figure represents less than 2% of annual plastic waste and approximately 8% of all mismanaged plastic waste (OECD, 2022a).

The calculation for plastic leakage into aquatic environments requires numerous caveats, the OECD's own reconciliations of prior studies suggests a sizable uncertainty range of four million to nine million metric tons. Individual studies, which utilize a variety of various methods and base years, are even more diverse; in certain studies, annual aquatic leakage estimates range as high as 5–13 million metric tons (Jambeck et al., 2015) or even 19–23 million metric tons (Borrelle et al., 2020).

The dispersion in estimates occurs as the transport of plastics in the environment is extraordinarily complex and the current understanding of the behavior of plastics released into aquatic environments is incomplete.

Not all plastic waste leakage into aquatic environments reaches the ocean. In fact, contrary to popular perception, less than 30% does. The majority is leaked into freshwater sources, where high-density plastic polymers such as polyethylene terephthalate (PET) or polyvinyl chloride (PVC) sink to river and lake beds. Lighter plastic polymers such as low-density polyethylene (LDPE), or air-filled plastics (e.g. bottles), are gradually transported to the coastal oceans.

The OECD estimates that the oceans contain approximately 30 million metric tons of plastic, with annual inflows of slightly less than two million metric tons.

We leverage our Plastic Kaya Identity to forecast the growth in future ocean plastic. A simple and illustrative exercise based on the OECD's baseline scenario, which (as a reminder) estimates approximately 80 million metric tons of annual mismanaged plastic waste in 2019, and using our Plastic Kaya Identity, results in an estimate of around 100 million metric tons of annual mismanaged plastic waste in 2060.

We first calculate the percentage of mismanaged plastic waste that reached the ocean in 2019 at approximately 2.3%. If we hold this figure constant over our forecast horizon, we can create both flow and stock estimates for plastic pollution in the ocean. Using these assumptions in the baseline scenario, the amount of plastic in the ocean would quadruple by 2060, rising from 30 million metric tons to approximately 120 million metric tons.

> “
> The OECD estimates that the oceans contain approximately 30 million metric tons of plastic

Measuring aquatic biomass

Forecasting the amount of fish biomass is also difficult. To state the obvious, fish move around a lot and there is also significant debate about the quantum of mesopelagic fish that live 200 to 1000 meters below the ocean's surface.

With fish off the menu, we turn our attention to what is arguably the poster child of the oceans – the whale. Estimating the biomass of the ocean's whales is also fraught with difficulty. To make our estimates, we turn to data from the International Whaling Commission (IWC) whose 2017 Scientific Committee attempted to harmonize data across more than a dozen species (including Blue, Fin, Gray, Minke and Humpback varieties). The data have their limitations as estimates are typically geographically bound and time-limited. In addition, for any given estimation, the 95% confidence interval presents a range where the upper bound is typically two-to-five times larger than the lower bound (IWC, 2019).

With these caveats in mind, we aggregate the relevant population estimates in combination with the International Whaling Commission's figures for adult whale weight per species. This analysis suggests a global whale population of slightly less than two million mammals and a total whale biomass of approximately 88 million metric tons. To avoid further complexity and assumptions, we do not make any estimates as to how whale populations and biomass develop over the forecast period to 2060.

Since the data for both ocean plastic and whale biomass are contingent upon several significant assumptions, we refrain from sensational statements. Instead, we compare our estimate of 2060 ocean plastic tonnage without further policy action (approximately 120 million metric tons) to our estimate of whale biomass (approximately 88 million metric tons). We therefore find it probable that, without additional policy action by 2060, there could be more plastic metric tonnage than whale biomass in the sea.

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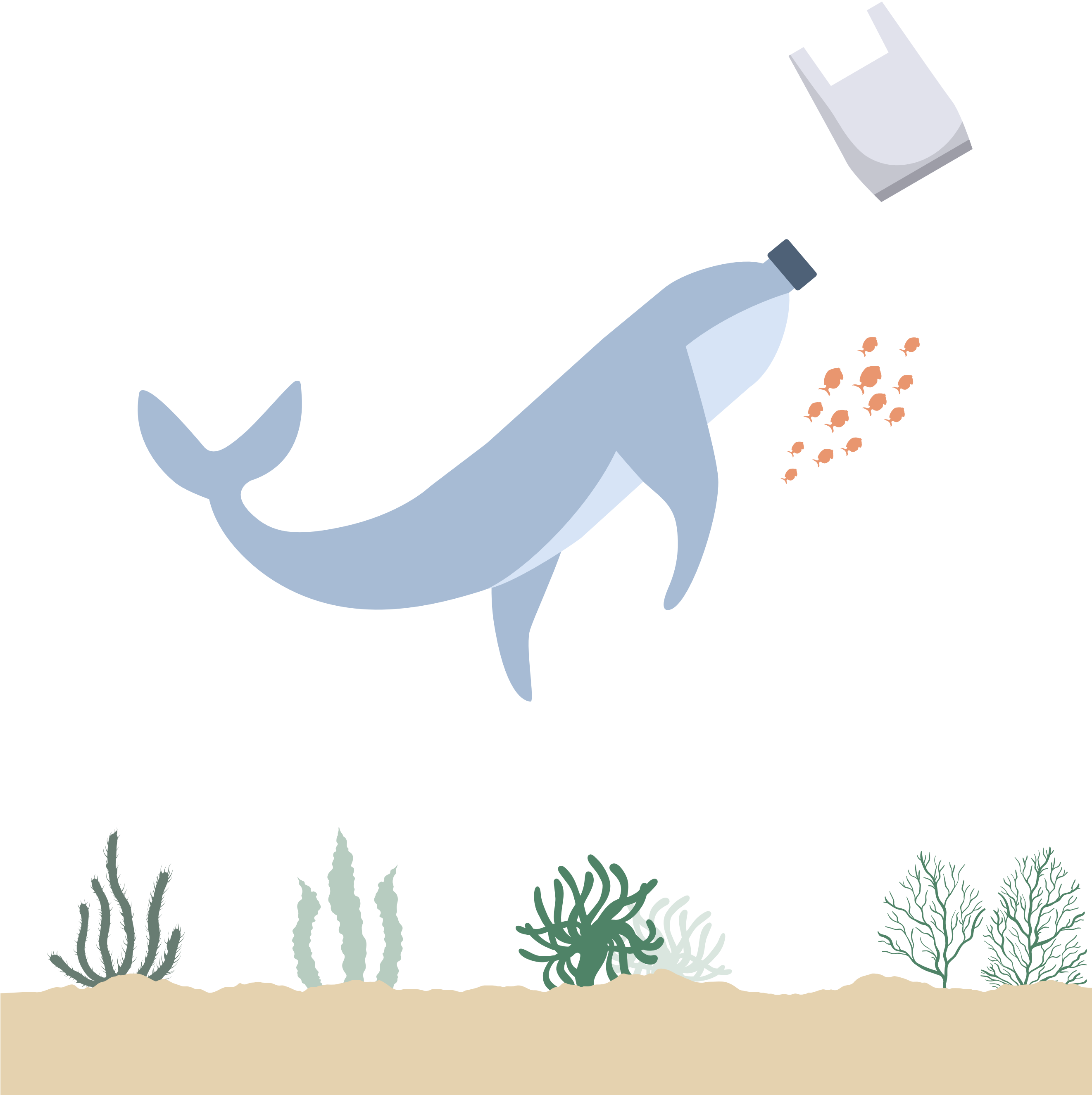
Without additional policy action by 2060, there could be more plastic metric tonnage than whale biomass in the sea




South_agency, Getty Images

Adaptation and mitigation

Mitigation and adaptation in a climate context

For this report, we draw on the climate concepts of mitigation and adaptation and apply them in a plastic pollution context. Climate mitigation and adaptation are two distinct concepts that cover different aspects of addressing climate change.

Climate mitigation refers to efforts aimed at reducing or preventing greenhouse gas emissions. Mitigation strategies include:

- Transitioning to renewable energy sources such as solar, wind and hydroelectric power.
- Improving energy efficiency in, for example, buildings, industries, transportation and appliances.
- Implementing sustainable land use practices by protecting forests, promoting reforestation and implementing sustainable agricultural practices.

Climate adaptation refers to minimizing the impacts of climate change by adjusting and preparing for its effects. Adaptation strategies include:

- Enhancing infrastructure resilience to withstand effects such as rising sea levels, increased temperatures and extreme weather events.
- Water management to ensure sustainable water resources management in the face of changing rainfall patterns and increased water scarcity.
- Agricultural adaptation by helping farmers adapt to changing growing conditions, such as modifying crop varieties, implementing water-efficient irrigation techniques and soil conservation methods.

Key points:

- Mitigation strategies aim to restrain plastic demand and reduce the plastic waste intensity of GDP. Adaptation strategies focus on the management of plastic waste, reducing mismanaged plastic waste as a percentage of total plastic waste.
- Not all mitigation strategies create better outcomes for people and the planet. The products that replace plastic can have inferior environmental profiles. Furthermore, bioplastics often compare unfavorably with fossil-based plastics.
- Among the adaptation strategies, improving waste-management infrastructure offers the best cost-benefit profile. Increased recycling is not a panacea. Plastic's diversity and toxicity ensures that approximately 40% of plastic collected for recycling is later incinerated or sent to landfills. Plastic removal is a key part of the pathway to net zero plastic pollution, but comes at an exorbitant cost relative to preventing plastic leakage.

Mitigation

Mitigation strategies aim to restrain plastic demand and disincentivize the production and use of fossil-based plastics. Instruments include legislation, taxation, the development of bioplastics and measures to increase the lifespan of plastic products. These actions combine in their attempt to reduce the plastic waste intensity of GDP.

Legislation

Legislating the reduction or non-use of plastic is a direct mechanism to restrain plastic demand and disincentivize the production and use of plastics, thus lowering the plastic waste intensity of GDP. There are several existing policy actions around the world. For example, in England, a ban is to be placed on a range of single-use plastics as of October 2023. The ban includes single-use plastic plates, trays, bowls, cutlery, balloon sticks, and certain types of polystyrene cups and food containers.

It is estimated that England uses 2.7 billion items of single-use cutlery (most of which are plastic) and 721 million single-use plates per year. By way of illustration, if 2.7 billion pieces of cutlery were lined up, they would go around the world over eight and a half times (UK Government, 2023).

In the European Union, regulations proposed in 2022 include banning single-use packaging for food and beverages when consumed inside restaurants and cafes, single-use packaging for fruits and vegetables, miniature shampoo bottles and other miniature packaging in hotels (EU Commission, 2022). This mitigating legislation is accompanied by various adaptation policy measures, e.g. measures aimed at making packaging fully recyclable by 2030 via design criteria for packaging and creating mandatory deposit return systems for plastic bottles and aluminum cans. There is an inherent logic in reducing single-use plastics, as reuse keeps resources functioning at a higher value in the economy and avoids losing the economic value of manufactured goods after a single use.

While legislation that restrains plastic demand mechanically lowers the plastic waste intensity of GDP, it does not necessarily guarantee better outcomes for people and the planet. Put simply, plastic is widely used because it has many valuable properties. For example, plastic packaging contributes to the reduction of food spoilage by offering a physical protective barrier to prevent defects and reduce the impact of environmental factors, such as oxygen and humidity. According to one study, sending one kilogram of food waste to landfill has a similar carbon footprint to landfilling 25,000 500ml plastic bottles (Tylenda et al., 2022). Thus legislation that seeks to restrain plastic demand and disincentivize the production and use of plastics can have unfavorable secondary effects.

Certain plastic substitutions can also exhibit unfavorable people and planet dynamics. For example, a study from the Danish Environmental Protection Agency found that a cotton tote bag would need to be used over 150 times to have the equivalent climate impact as a LPDE plastic carrier bag (EPA Denmark, 2018). Furthermore, cotton has additional negative externalities. Despite being grown on less than 3% of the world's agricultural land it consumes over 15% of all insecticide usage as well as substantial volumes of water. As a result, the same Danish study suggested to account for these additional people and planet impacts a cotton tote bag would need to be used over 20,000 times to have the same overall impact as a LPDE plastic carrier bag. Hence, arguably, plastic bags are a more people and planet friendly solution than their oft cited fashionable alternative. This dynamic is also evident in several other plastic substitutions.

To inform the substitution dialogue, significant research has been conducted. The UNEP has developed ten factors to consider (UNEP, 2021), while the World Bank has sought to simplify the choice of alternatives by creating the Plastic Substitution Trade-off Estimator (World Bank, 2022). Substitutions can also be geographically dependent. For example, when replacing plastic with paper, sustainable sourcing of wood is a critical concern especially in the Global South, where certification schemes are less developed and paper demand can drive deforestation. Legislating the reduction or non-use of plastic, while lowering the plastic waste intensity of GDP can have unintended unfavorable consequences.

> “
> **By way of illustration, if 2.7 billion pieces of cutlery were lined up, they would go around the world over eight and a half times**

“

Legislating the reduction or non-use of plastic, while lowering the plastic waste intensity of GDP can have unintended unfavorable consequences

Taxation

Increasing the cost of plastic through taxation is a direct mechanism to restrain plastic demand and disincentivize the production and use of plastics, thus lowering the plastic waste intensity of GDP. There are several existing policy actions, which predominantly focus on plastic packaging.

For example, in the United Kingdom, 2022 legislation applies a GBP 200 a metric ton tax chargeable to plastic packaging components. The tax is chargeable if the proportion of recycled plastic in the finished component, when measured by weight, is less than 30 percent of the total amount of plastic in the component. Given the recency of the tax it is not yet possible to assess whether the tax has impacted the plastic waste intensity of GDP. However, it is notable that the tax is approximately just 25% of the level modelled in the OECD's moderately ambitious scenario (UK Government, 2021).

A different approach has been pursued in the European Union. Technically, it is not a tax, but is instead best described as a contribution from the member states to the European Union budget based on the amount of non-recycled plastic packaging waste produced by each country. The contribution is set at EUR 800 per metric ton, which is approximately 90% of the level modeled in the OECD's moderately ambitious scenario (KPMG, 2021). Various member states have responded to this contribution with the intention of introducing plastic taxes to fund the cost. For example, Spain has set a tax of EUR 450 per metric ton targeting single-use plastic packaging (KPMG, 2021). The contribution-based approach has also drawn some criticism as the contribution has a revenue focus and does not directly impact the plastic value chain – such as taxing plastic production, consumption or disposal (Powell, 2018). Hence its potential to change consumption behaviors and lower the plastic waste intensity of GDP is limited, if not accompanied by additional country level action such as in Spain.

Applied correctly, taxation can support circularity and promote reuse. Circular systems tend to be more labor intensive than linear systems, which are more resource intensive. Therefore, shifting the fiscal burden from labor to resources improves the economics of reuse. A simple implementation is a virgin plastic tax that reduces the price gap between virgin single-use products and reuse schemes or plastic alternatives. Funds raised for reuse schemes between 2015 and 2021 are estimated at over USD 1 billion, mostly in the United States of America, Canada and Europe (World Economic Forum, 2022).

Bioplastics

Bioplastics are typically plastic materials that are produced from renewable biomass sources, such as vegetable fats and oils, sawdust or even recycled food waste. They offer an alternative to fossil-based plastics. Their allure is straightforward as they suggest plastic can be made from non-virgin and/or easier-to-replenish materials. Bioplastics therefore have the potential to reduce fossil-based plastic use and the plastic waste intensity of GDP.

Currently, bioplastics represent less than 0.5% of global plastic usage (European Bioplastics, 2019) and, even in the OECD's most aggressive policy scenarios, they are forecast to make up only a mid-single digit of plastic usage by 2060 (OECD, 2022b). The impact of bioplastics on people and the planet is also ambiguous, predominantly because many bioplastics are surprisingly resistant to microbial degradation in a natural environment. Thus, if their waste disposal is mismanaged, they can have significant negative interactions with terrestrial and aquatic environments – just like their fossil-based counterparts. To illustrate, polylactic acid (PLA) polymers, which are arguably the most price-competitive synthetic bioplastic, require industrial composting temperatures to be more than 60°C, a temperature not found in terrestrial and aquatic environments (Naser, Deiab and Darras, 2021).

Bioplastics face numerous other challenges, including but not limited to cost, efficiency and ethics. In terms of cost, bioplastics often cost substantially more that their nearest fossil-based peers. For example, polybutylene succinate (PBS), an aliphatic copolyester with a flexible molecular structure, has failed to displace fossil-based LDPE – which is used for items such as carrier bags. Furthermore, fossil-based polypropylene (PP) outcompetes PBS in food packaging (Rosenboom, Langer and Traverso, 2022).

In terms of efficiency, despite not being fossil-based, the bioplastic manufacturing processes can often have cradle-to-gate carbon footprints that are equal or even higher than their fossil-based peers. For example, bio polyethylene terephthalate (bioPET) shares identical properties to fossil-derived polyethylene terephthalate (PET), but, despite its alternative production method, it also has a near identical cradle-to-gate carbon footprint. Furthermore, bioPET exhibits a less favorable cradle-to-gate sulfur dioxide profile, which is a contributing cause of water acidification. As a result bioPET has not made significant inroads into the PET core markets, such as single-use plastic drink bottles (Rosenboom, Langer and Traverso, 2022).

> “
> In terms of cost, bioplastics often cost substantially more that their nearest fossil-based peers

In terms of ethics, many bioplastics utilize first-generation biomass, which is often edible. This is controversial as bioplastics may compete with food production and could therefore contribute to food inflation as well as exacerbate social challenges, such as increased economic poverty. First-generation biomass can also contribute to negative biodiversity outcomes, as increased cropland area can drive deforestation, which has harmful biodiversity consequences as well as triggering carbon release from felled trees.

Durability

One driver of the plastic waste intensity of GDP is durability. To illustrate, if a consumer product lasts four years as opposed to two years, then half the amount of plastic is required over a four-year-cycle. Hence increased durability and lifecycles mechanically reduce the demand for plastic and thus subsequent plastic waste. Plastic lifespans are often determined by use case, e.g. packaging has an average lifespan of only half a year, textiles five years, and industrial machinery 20 years (Geyer, Jambeck and Law, 2017). This underpins packaging’s significant share – in excess of 40% – of annual plastic waste.

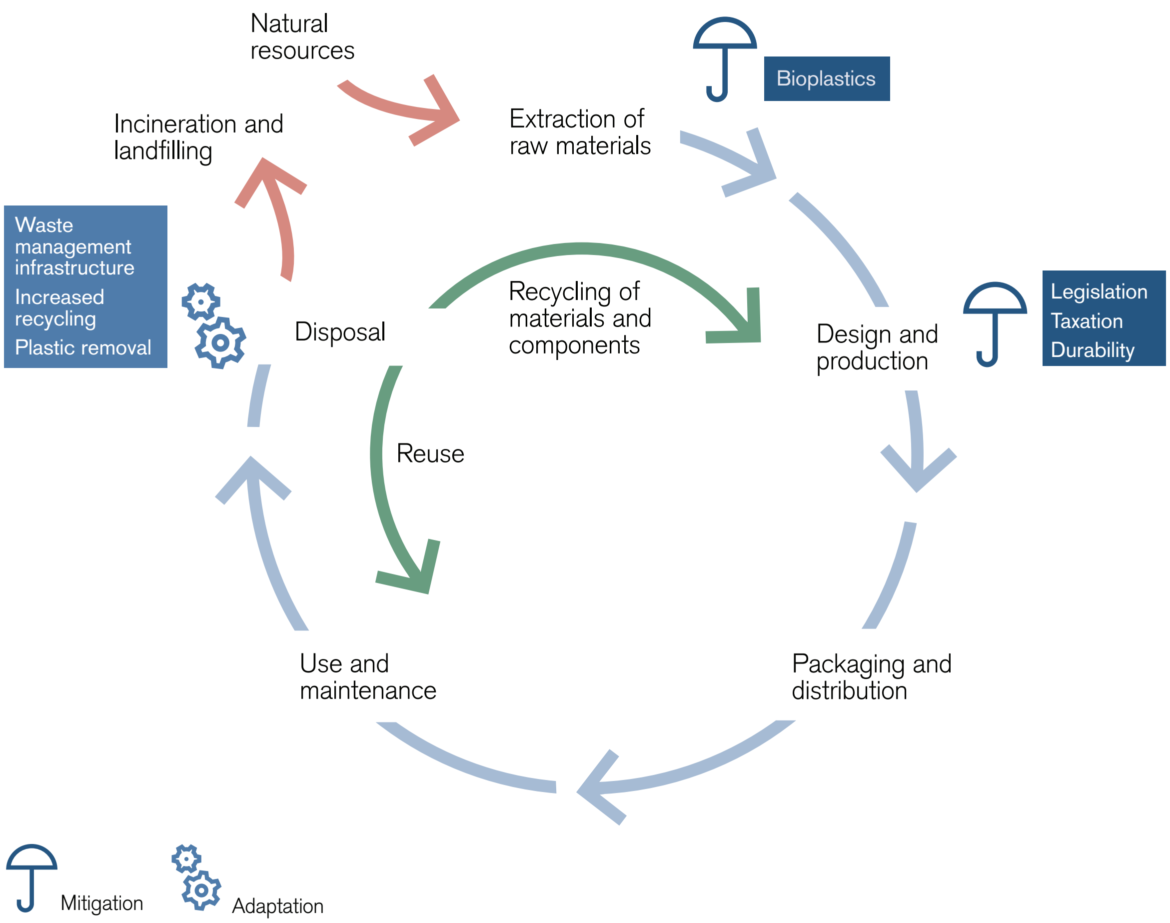
The short lifespan of packaging has consequences for adaptation actions, such as recycling. The widespread use of PET, LDPE, PP and high density polyethylene (HDPE) polymers in packaging means that household recycling education and capacity need to reflect these products and polymers. Differing product lifespans also ensure that, while packaging is a large part of annual plastic waste, it is a much smaller part of the current global plastic stock. Hence, in a counterfactual scenario where all plastic production ceases, the resultant plastic waste over the coming decades would come from plastic polymers with longer lifecycles than those used for packaging and would thus trigger different recycling and disposal needs.

Somewhat counterintuitively, increased durability can increase the challenges of mismanaged plastic waste. Though not perfectly correlated, an increased functioning lifespan can also lead to slower degradation in the event of mismanagement. One reason is that degradation is closely related to surface area. Thus thicker more durable plastic structures take longer to decompose than their thinner counterparts. For example, a common HDPE produce bag has a thickness of 0.015 mm and dimensions of 25 cm × 38 cm. This corresponds to a total surface area of 3,800 cm^2 and a volume of 2.9 cm^3. A spherical bead with the same polymer volume would have a surface area of less than 10 cm^2 and would therefore have an initial degradation rate nearly 400 times slower than that of the bag (Chamas et al., 2020). As a result, some attempts to increase durability and lower the plastic waste intensity of GDP can inadvertently increase the negative biodiversity outcomes associated with the remaining mismanaged plastic waste.

Adaptation

Adaptation strategies acknowledge that plastic has many favorable qualities and thus focus on how to manage plastic waste effectively and responsibly. Adaptation strategies seek to close leakage pathways and aim to decrease and, where possible, eliminate mismanaged plastic waste by investing in waste management infrastructure, increasing recycling and the proactive removal of plastic from the environment. These actions combine in their attempt to reduce mismanaged plastic waste as a percentage of total plastic waste.

Mitigation and adaptation actions can occur across the plastic lifecycle



Source: UNEP, Credit Suisse

Waste management infrastructure

The largest potential contributor to reducing mismanaged plastic waste as a percentage of total plastic waste is an improvement in waste management infrastructure, i.e. waste collection, sanitary landfills and incineration – the latter of which can occur either with, or without, energy recovery.

The template for broadly successful adaptation already exists. In the OECD countries, just 6% of plastic waste is mismanaged, with over 50% being sent to sanitary landfills and a further 25% being incinerated in controlled industrial environments. In contrast, non-OECD plastic waste mismanagement rates are more than 35% so that 90% of global mismanaged plastic waste tonnage stems from non-OECD countries (OECD, 2022a). Furthermore, it has been estimated that nearly 90% of the plastics entering the ocean comes from just ten rivers, all located in Asia or Africa (Schmidt, Krauth and Wagner, 2017).

However, closing leakage pathways is not straightforward as waste management infrastructure can be costly (though ultimately GDP-additive over the medium term), and policy actions are only as effective as the bureaucracy that implements them. In fact, it is estimated that there are currently about two billion people not connected to waste collection systems (UNEP and ISWA, 2015). Plastic waste management infrastructure is also inseparable from mixed municipal waste systems which can complicate plastic-specific cost-benefit analysis. Even in its current imperfect state, waste collection is already a major cost for municipalities, typically averaging 10%–20% of council budgets in non-OECD countries (Kaza et al., 2018).

Research suggests that mixed waste collection costs between USD 40 and USD 86 per metric ton, with additional costs if recycling is pursued. Landfilling typically costs between USD 28 and USD 34 per metric ton, while incineration with energy recovery can cost between USD 90 and USD 150 per metric ton. These figures are not financially immaterial and require significant upfront capital expenditure (Soós, Whiteman and Gavgas, 2022).

A Brazilian case study in regard to implementing successful waste management in non-OECD countries found that, between 2000 and 2010, the percentage of solid waste going to sanitary landfills increased from 38% to 57% (Brazilian Government, 1998). This was in part driven by a 1998 federal law that made the inappropriate disposal of solid waste an environmental crime. This was supported by inspections of municipal bodies, closures of open-air dumps and increased financial support for new sanitary landfills (OECD, 2022c).

Though complex, the establishment of successful waste management infrastructure is the largest potential contributor to reducing mismanaged plastic waste as a percentage of total plastic waste.

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> The outlook for recycling is somewhat more favorable as policy intervention is increasing the demand for recycled plastics

Increased recycling

Approximately 15% of annual plastic waste is recycled, a figure lower than the percentage of mismanaged plastic waste (22%, OECD, 2022a). Recycling has the potential to reduce mismanaged plastic waste as plastic waste is appropriately disposed of rather than leaked into terrestrial and aquatic environments. Recycling has other additional favorable dynamics, such as the production of secondary plastics and associated revenue streams. Recycling reduces the need to create virgin plastic from fossil-based sources. However, the secondary plastic market is currently underdeveloped and secondary plastics currently only account for 6% of total global plastic production, despite absolute volumes quadrupling over the past two decades (OECD, 2022a).

Unfortunately, recycling is not a panacea and there are numerous barriers to rapidly increasing recycling. These include, but are not limited to, the diversity of plastic polymers, product design, and plastic’s toxicity and flammability. Taking each in turn, there are thousands of different plastics, many of which include one or more of the 13,000 chemical substances that have been identified as associated with plastics as monomers, additives or processing aids. Many of these products are not easily recycled together (UNEP, 2023). Product design legislation could disincentivize or even outlaw certain practices. As a simple illustration, widely used polymers such as HDPE, PVC, LDPE, PP and polystyrene (PS) must all be separated for mechanical recycling.

The recycling process itself is also fraught with difficulty as, unlike metal and glass, plastics are not inert. Their toxicity and flammability create numerous risks for people and the planet, such as unscheduled chemical releases and fire risk. Furthermore, there is an under-appreciated tension between globalized consumer goods supply chains and the heterogeneity of local waste management systems that have to deal with plastic waste. These dynamics persuaded a study commissioned by the Canadian government to conclude that “the vast majority of plastic products and packaging produced” are not suitable for being recycled into food-grade packaging (Stina Inc. and ECCC, 2021).

One oft-cited breakthrough is chemical recycling – which differs to conventional mechanical recycling, where plastic waste is ground and melted. Chemical recycling holds potential for processing mixed plastics, but is also not without controversy. For example, a 2021 report from Reuters exposed failings at an advanced chemical recycling program in Idaho, United States, that sought to convert mixed plastic waste into diesel. Owing to an inability to process certain plastics, such as household plastic wrap (PVC), its failure led to its closure in favor of sanitary incineration as part of a waste-to-energy project (Brock, Volcovici and Geddie, 2021). Currently, chemical recycling is typically considered to be in the pilot or demonstration phase.

The outlook for recycling is somewhat more favorable as policy intervention is increasing the demand for recycled plastics. For example, in the European Union, the single-use plastics directive requires plastic bottles to contain at least 25% recycled content by 2025 and 30% recycled content by 2030 (EU, 2019). Such legislation creates a “bid” for recycled plastics, which can underpin capital investment in recycling facilities as well as research and development spending in technological improvements.

The sum of these dynamics is nuanced. Under OECD modeling, the current plastic waste trajectory will lead recycling rates to increase from approximately 15% of all plastic waste to 30% of plastic waste by 2060 (OECD, 2022b). However, material problems are likely to persist. The recycling residue rate – where collected plastic is unrecyclable and thus landfilled or incinerated – is likely to remain elevated. Approximately 40% of plastic collected for recycling is later sent to landfill or incinerated. Unless there are material unforeseen technological developments, this residue rate is unlikely to change significantly from its current level. In sum, despite its intuitive appeal, recycling is only a partial adaptation response to reduce mismanaged plastic waste as a percentage of total plastic waste.

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Despite its intuitive appeal, recycling is only a partial adaptation response to reduce mismanaged plastic waste

Plastic removal

Our findings demonstrate that, under all viable scenarios, the annual volume of plastic waste will increase significantly by 2060. In our baseline scenario, annual mismanaged plastic – also termed plastic pollution – increases from approximately 80 million metrics tons to 100 million metric tons by 2060. Even in our moderately and highly ambitious scenarios, where annual plastic pollution volumes decrease by 2060, their culminative effect ensures that the stock of plastic pollution in terrestrial and aquatic environments increases compared to current levels.

Drawing on the net zero climate parallels, which require CO_2 removal through nature-based or engineering solutions, a pathway to net zero for plastic pollution would also require plastic removal.

Earlier in this chapter, we outlined various waste management infrastructure costs that, if appropriately deployed, prevent plastic waste from becoming plastic pollution. The most costly – recycling – had financial costs that were approximately in the low USD hundreds per metric ton of plastic processed. In contrast, plastic removal is expensive. The most straightforward approach – terrestrial litter collection – is estimated to cost USD 1,000–2,000 per metric ton (Soós, Whiteman and Gavgas, 2022).

Various studies have pointed to even higher costs when addressing aquatic plastic pollution. For example, a Korean study estimated shoreline cleaning of plastic pollution to cost USD 1,300 per metric ton, an Alaskan study estimated almost USD 2,400 per metric ton and more specific plastic removals such as addressing derelict fishing gear have been shown to have costs as high as USD 25,000 per metric ton (Hwang and Ko, 2007; Raaymakers, 2007).

While plastic removal from terrestrial and aquatic environments is an essential part of a pathway to net zero plastic pollution, it is far more expensive than stopping plastic leakage in the first place. To use a simplistic analogy, if a bath is overflowing, first turn off the tap before you start frantically grabbing buckets. Despite this, plastic removal efforts should not cease as the negative climate, biodiversity and social impacts from plastic pollution have, arguably, an even greater financial cost than that of plastic removal.


Visoot Uthairam, Getty Images

Conclusions

We conclude that plastic is – and will very likely will continue to be – ubiquitous in modern life, ranging from packaging to textiles to consumer products due to its applicability, value, and durability.

Our innovative application of the Kaya Identity within a plastic context, supported and powered by the OECD's Global Plastics Outlook Database, finds that, under any almost any conceivable scenario, plastic usage and plastic waste will increase on a per annum basis between now and 2060.

Key points:

- Our innovative application of the Kaya Identity within a plastic context finds that plastic usage, and thus plastic waste, will almost certainly increase on a per annum basis between now and 2060.
- Mitigation measures to restrain plastic demand and lower the plastic waste intensity of GDP are part of the journey toward net zero plastic pollution. However, the more significant contributor is adaptation, i.e. finding ways to live with plastic and to reduce mismanaged plastic waste as a percentage of total plastic waste.
- The negotiations for a global plastics treaty could yield the most significant sustainability-focused multilateral proposal since the Paris Agreement in 2015. After all, the Paris Agreement inspired the climate's race to net zero, and provided the concepts that we have adopted and adapted for this report on plastic pollution.

> “We find the more significant contributor to plastic pollution net zero is adaptation

Mitigation measures to restrain plastic demand and disincentivize the production and use of plastics, thus lowering the plastic waste intensity of GDP, are undoubtedly part of the journey toward net zero plastic pollution. Using the highly ambitious scenario from the OECD, various mitigation efforts would reduce the absolute volume of annual plastic waste by approximately one-third compared to the baseline scenario.

However, we find the more significant contributor to plastic pollution net zero is adaptation.

Breaking down our Plastic Kaya Identity demonstrates that rising populations and rising standards of living will correlate with increasing plastic waste volumes. Thus adapting and finding ways to live with plastic and reduce mismanaged plastic waste as percentage of total plastic waste is critical to stem the flow of plastic into terrestrial and aquatic environments.

In this paper, we have aimed to provide a balanced view across both potential mitigation and adaptation measures. For example, we have noted the challenges that arise from mandating the discontinuation of plastics as certain replacement solutions may be no better for people and the planet. We have highlighted the limits of technology, such as bioplastics and chemical recycling, and have demonstrated that prevention is better than treatment as it is more economical to stem the flow of plastics into the natural environment than to remove them once they have already leaked.

That said, to achieve net zero plastic pollution, the removal of plastic from natural environments is nevertheless a necessary part of the pathway. Though it is expensive to remove plastic from natural environments, it is, in a wider economic context, affordable. For example, if we take our 2060 baseline forecast of 120 million metric tons of ocean plastic, even at an extortionate cost of USD 5,000 per metric ton, the cost to remove all ocean plastic is less than 1% of global GDP.

> “
> **To achieve net zero plastic pollution, the removal of plastic from natural environments is nevertheless a necessary part of the pathway**

Readers may note that the plastic pollution estimates in this paper are generally lower than in many previous studies. This is particularly true for ocean plastic, where our headline statement that "without additional policy action, by 2060 there could be more plastic tonnage than whale biomass in the sea" is materially less dramatic than the infamous (and subsequently disproved) 2016 statement from the Ellen MacArthur Foundation paper, which said that, by 2050, there would be more plastic tonnage than fish in the sea (Ellen MacArthur Foundation, World Economic Forum and McKinsey & Company, 2016).

Much of our conservatism originates from our starting point. The OECD's research estimates that approximately six million metric tons of plastic leaks into aquatic environments per annum. This is materially lower than prior studies, which utilize a variety of various methods and base years, and yield aquatic leakage estimates that range as high as 5–13 million metric tons (Jambeck et al., 2015) or even 19–23 million metric tons (Borrelle et al., 2020). Our 2060 figures for plastic pollution – and thus mismanaged plastic pollution – are also lower than the OECD's paper, which detailed numerous policy scenarios (OECD, 2022b). The primary reason for this is that our forecasts for global GDP growth are approximately one percentage point lower per annum than those used in the OECD's study. We view our estimations as suitably conservative.

Regardless, it is apparent that there needs to be significant additional research conducted on the topic of plastic pollution, particularly on leakage pathways and understanding how plastic waste becomes plastic pollution as well as its complex migration pathways through our terrestrial and ocean environments.

Finally, as we look to the future, we express cautious optimism. We believe that the negotiations for a global plastics treaty initiated by the United Nations Environment Assembly have the potential to be the most significant sustainability-focused multilateral proposal since the Paris Agreement in 2015.

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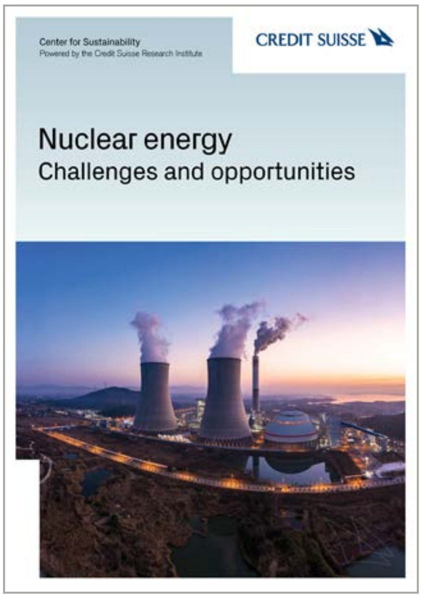

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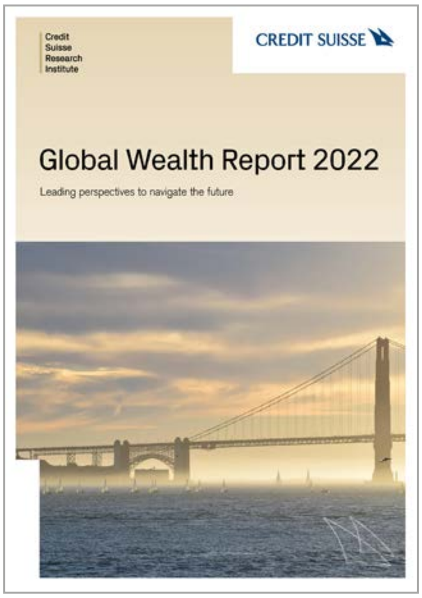

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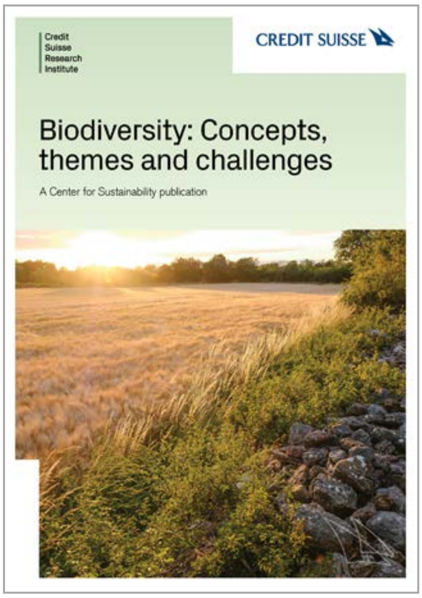

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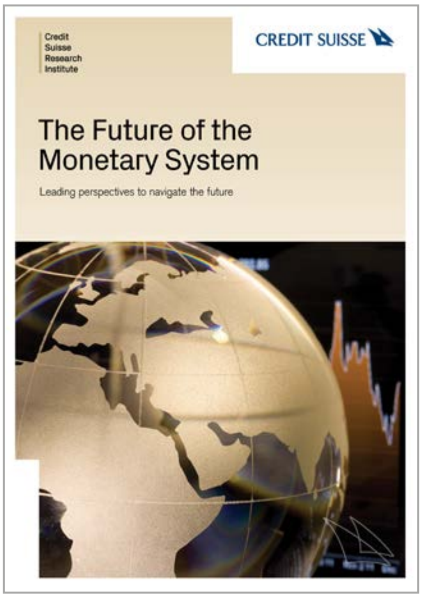

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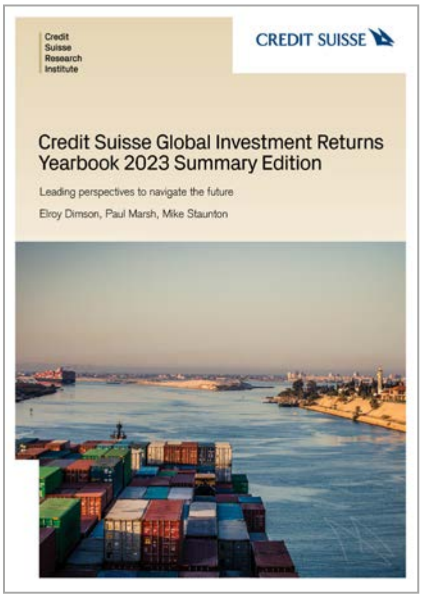

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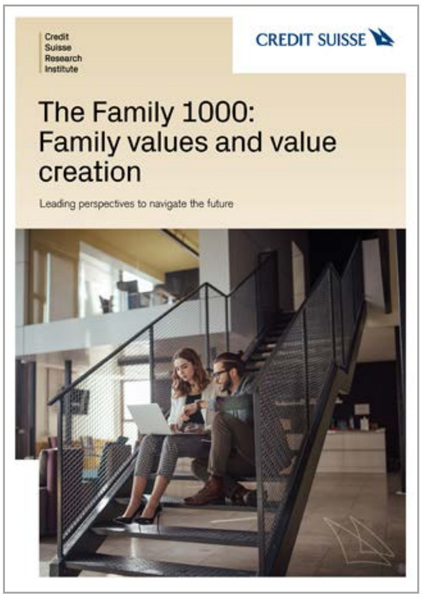

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