A REPORT FOR WWF BY

Dalberg

PLASTICS: THE COSTS TO SOCIETY, THE ENVIRONMENT AND THE ECONOMY

Acknowledgements

The report was written by Dalberg Advisors, and the team comprised of Wijnand DeWit, Erin Towers Burns, Jean-Charles Guinchard and Nour Ahmed.

Dalberg Advisors

Dalberg Advisors is a strategy consulting firm that works to build a more inclusive and sustainable world where all people, everywhere, can reach their fullest potential. We partner with and serve communities, governments, and companies providing an innovative mix of services – advisory, investment, research, analytics, and design – to create impact at scale.

WWF

WWF is one of the world's largest and most experienced independent conservation organizations, with over 5 million supporters and a global network active in more than 100 countries.

WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

Published in September 2021 by WWF – World Wide Fund For Nature (Formerly World Wildlife Fund), Gland, Switzerland.

Design: Ender Ergün

A REPORT FOR WWF BY

Dalberg

WWF International
Rue Mauverney 28,
1196 Gland, Switzerland.
www.panda.org

Dalberg
Rue de Chantepoulet 7
1201 Geneva, Switzerland
www.Dalberg.com

CONTENTS

WWF'S CALL FOR COLLECTIVE GLOBAL ACTION

The unique properties of plastic have led to it taking an important role in society. Unfortunately, the production, consumption and disposal of this material impose significant negative impacts on society, the environment, and the economy. These costs are not accounted for in the current price of virgin plastic. As this report shows, the cost of plastic to the environment and society is at least 10 times higher than its market price paid by primary plastic producers, generating significant external costs for countries. The failure of governments to better understand the real costs of plastic has led to poor management of this material, and growing ecological, social, and economic costs for countries. The cost of the plastic produced in 2019 will be at least US$3.7 trillion (+/-US$1 trillion) over its estimated lifetime. The current global approach to addressing the plastic crisis is failing. Unless urgent action is taken, the societal lifetime cost of the plastic produced in 2040 could reach US$7.1 trillion (+/-US$2.2 trillion), equivalent to approximately 85% of global spending on health in 2018 and greater than the gross domestic product (GDP) of Germany, Canada, and Australia in 2019 combined.

Now, is a critical moment for governments to ensure that all actors in the plastic system are held accountable for the cost imposed by the plastic lifecycle on nature and people.

WWF CALLS ON ALL GOVERNMENTS TO:

AT THE INTERNATIONAL LEVEL

- **Start negotiations of a legally binding international treaty** to tackle all stages of the plastic lifecycle, stopping the leakage of plastic pollution into the oceans by 2030, thereby significantly contributing to Sustainable Development Goals (SDGs) and paving the way for an accountability framework to address plastic pollution on a global level. The treaty should:
- **Establish national targets and action plans** for plastic reduction, recycling and management in line with global treaty commitments, including transparent reporting mechanisms that recognise the transboundary nature of the problem.
- **Establish harmonised definitions and standards** to define products and processes, applied across markets and along the plastic value chain.
- **Implement sufficient monitoring and compliance measures** for all policies related to the production, collection and management of waste by all stakeholders in the plastic system, supported by a shared global reporting and monitoring framework.
- **Establish a global scientific body to assess and synthesise best available research on plastic and microplastics in nature.** Such a body would enable the scientific community to pool resources and develop common standards for measuring and reporting on plastic pollution leakage.
- **Provide implementation support both in the form of a financial mechanism as well as technical support,** including sharing of the best practice among states.
- **Provide support for increased** research into, reporting of, and accounting for costs associated with the plastic lifecycle from the academic community.

AT THE NATIONAL LEVEL

- **Deploy appropriate policy instruments** that internalise the full cost of plastics and incentivise waste reduction, implementation of reuse models, the creation and use of recycled plastic over new plastic, and the development of viable alternatives to plastic that have smaller environmental footprints.
- **Collaborate with industries and civil society groups** to ensure a systems-based approach that addresses plastic production, consumption, waste management, and recycling as a singular system, and refrain from individual, fragmented or symbolic policy actions.
- **Invest in ecologically-sound waste management systems** domestically and in countries where a nation's plastic waste is exported for disposal, thereby locking in long-term economic and environmental benefits.
- **Legislate effective extended producer responsibility (EPR)** as a policy mechanism for all plastic-producing sectors to ensure the greater accountability of companies in the collection, reduction, recycling, and management of the plastic waste originating in their trade chains.
- **Work at appropriate subnational levels** to establish robust management plans and transparent accounting mechanisms that prevent plastic leakage into water systems or other mismanaged waste disposal mechanisms.

Las Vegas, Nevada, USA, 2019 © shutterstock / John Dvorak

EXECUTIVE SUMMARY

Plastic plays many important roles, but its production, use and disposal impose countless negative impacts on society, with plastic pollution among the most pressing environmental issues of today.[1] Due to its seemingly cheap price and various uses, plastic has been increasingly used across millions of applications. As a result, plastic production has almost doubled over the past two decades.[2] The production of this plastic releases chemical pollutants and greenhouse gases (GHG) that can cause adverse health effects in humans and contribute to climate change.[3,4] Given that much of the plastic produced is designed to be used only once,[5] increasing plastic production will inevitably result in increases in plastic waste. This waste is either disposed of via processes that can also release chemical pollutants and contribute to climate change, or leaks into the environment, becoming plastic pollution. Today, more than 11 million tonnes of plastic enter the ocean every year.[6] Pollution in the ocean poses a threat to marine life,[7] impacting the provision of ecosystem services[8] and damaging key economic industries such as fisheries and tourism.[9]

These impacts generate significant costs for society that are not accounted for in plastic's market price: the lifetime[10] cost of the plastic produced in 2019 will be at least US$3.7 trillion (+/-US$1 trillion)[11] and more than the GDP of India.[12] Plastic appears to be a relatively cheap material when looking at the market price primary plastic producers pay for virgin plastic,[13] In 2019, the cost was just over US$1,000 per tonne.[14] However, this price fails to account for the full cost imposed across the plastic lifecycle. For example, the cost of GHG emissions from across the plastic lifecycle amounts to more than US$171 billion.[15] Furthermore, the management of plastic waste cost more than US$32 billion,[16] to collect, sort, dispose and recycle the huge quantities of plastic waste generated in 2019 alone.[17] Plastic takes hundreds to thousands of years to fully degrade and as it degrades, it breaks down into smaller and smaller particles making it hard to recover and remove plastic from the environment. Plastic will therefore remain in the environment to incur further costs. For example, it is estimated that the plastic produced in 2019 that becomes marine plastic pollution will incur a cost of US$3.1 trillion (+/-US$1 trillion) over its lifetime as a result of the reduction in ecosystem services provided by marine ecosystems.[18] There are also additional costs incurred from clean-up activities.

At the same time, a lack of data prevents cost estimates for all the negative impacts of plastic, so the true lifetime cost of plastic is even higher than the current estimate suggests. There are data gaps and limitations in understanding when it comes to the size and extent of the damage caused by the plastic pollution crisis. Therefore, the current estimate is the lower bound of the full cost imposed by the plastic lifecycle.

Without significant action, plastic production is expected to significantly increase, resulting in a corresponding rise in the cost imposed on society. The societal lifetime costs of the projected virgin plastic produced in 2040 (lifetime cost of plastic excluding the market cost) could reach more than US$7.1 trillion (+/-US$2.2 trillion), equivalent to approximately 85% of global spending on health in 2018 and greater than the GDP of Germany, Canada, and Australia in 2019 combined .[19] Plastic production is expected to more than double by 2040 and plastic pollution in the ocean is expected to triple.[20] At that point, plastic would account for up to 20% of the entire global carbon budget[21] and accelerate the climate crisis.

Many of the necessary global actions to tackle the plastic crisis are known, but current initiatives lack the necessary scale to drive systemic change, while regulatory approaches have been heterogenous and scattered, failing to target the fundamental problem drivers. Leading organisations [22,23,24] have proposed circular economy approaches to tackle the plastic crisis aiming to keep plastic within the economy and out of the environment. These approaches can effectively reduce the negative impacts of plastic, including reducing the annual volume of plastic entering oceans by 80% and GHG emissions by 25%.[25] However, the financial and technical resources required to undertake the overhaul in systems are preventing governments from acting. At the same time, there is currently no feedback loop from the adverse aspects of the plastic system because the lifetime cost of plastic is not fully accounted for in the market price. Therefore, there is a lack of incentive to implement the kinds of systemic changes required. The lack of comprehensive data also limits governments' understanding of the plastic crisis and ability to make informed decisions. Instead of taking a lifecycle approach, government efforts have often only tackled one stage of the plastic lifecycle or focused on a too narrow scope, such as banning single-use plastic bags.[26]

The transboundary nature of plastic requires a truly global response to effectively tackle the crisis, however, there is currently a notable lack of global coordination in plastic action. Plastic is transboundary in nature with the lifecycle of one item often split across various countries. Extraction of raw materials often happens in one country, conversion into plastic products in another, consumption in another, and waste management in another. Plastic pollution is also not constrained by national boundaries, because it migrates via water and air currents and settles at the seafloor. Therefore, a global response is needed to tackle the global plastic crisis. However, there is currently no global instrument established to specifically prevent marine plastic pollution or tackle plastic across its lifecycle.[27]

In recognition of these challenges, there are growing calls from civil society, companies and financial institutions to establish a new global treaty on marine plastic pollution. Such a treaty would enable governments to tackle the plastic crisis and reduce the cost that plastic imposes on society. A global treaty could provide a well-designed framework encompassing global coordination on definitions, policies, reporting, and implementation support to accelerate the transition to a circular economy for plastic. If developed effectively, it will act as a legally binding instrument that ensures accountability, encouraging and enabling countries to take the necessary steps to tackle the plastic crisis. Seventy five leading companies from across the plastics value chain have endorsed the Business Call for a UN Treaty on Plastic Pollution[28]. More than 2.1 million people from around the world have signed a WWF petition calling for a global treaty on marine plastic pollution.[29] Governments are beginning to respond. As of August 2021, a majority of the UN member states (104 countries) have explicitly called for a new global agreement.[30] **For a new treaty to be established, governments will have to start negotiations through the adoption of a formal negotiation mandate at the 5th session of the UN Environment Assembly in February 2022.**

3.7

TRILLION (US$)

THE LIFETIME COST OF THE PLASTIC PRODUCED IN 2019 WILL BE AT LEAST US$3.7 TRILLION (+/-US$1 TRILLION) AND MORE THAN THE GDP OF INDIA.

Sylhet, Bangladesh, 2015 © shutterstock / HM Shahidul Islam

CHAPTER 1: INTRODUCTION

The unique properties of plastic have led to it playing an important role in society. Plastic is a unique material; often lightweight, resilient, waterproof and cheap. These properties have established it as the material of choice for many different products, from clothing and scientific equipment to solar panels and car components. Plastic therefore plays many important roles in society. In particular, plastic has been used as an essential material in ensuring both food safety and food security; packaging of food products prevents food loss, waste, and contamination, protects foods from pests and diseases, and increases shelf life. Plastic has also played a crucial role in limiting the spread of COVID-19 and reducing fatalities from the disease;[31] most personal protective equipment and the medical equipment used to save lives are made entirely or partially of plastic. **As such, we are in the "age of plastic", with plastic production almost doubling over the past two decades[32] and expected to more than triple by 2050.[33]**

Increased production has led to a flood of plastic pollution entering the oceans. As plastic has become more important for society, plastic use, in particular single-use plastic, has risen. Much of the plastic produced is designed to be used only once.[35] This has led to a dramatic rise in plastic waste. Humanity now produces more than 200 million tonnes of municipal solid plastic waste annually. [36] This is equal to around 523 trillion plastic straws which if laid lengthwise could wrap around the world approximately 2.8 million times.[37] Waste management systems are inadequately prepared to deal with this large volume of plastic waste, resulting in an average of 41% of plastic waste being mismanaged.[38] Of this mismanaged waste, about 47% leaks into nature and becomes plastic pollution, often making its way into the ocean. More than 11 million tonnes of plastic enter the ocean every year.[39]

What is mismanaged plastic waste? Mismanaged plastic waste refers to any plastic waste that is openly burned or that is directly dumped or leaked into the environment.[40]

Plastic pollution causes countless detrimental impacts and has become a major global concern. Plastic pollution poses a threat to both people and the planet.[41] It also causes damage to economic industries, in particular fisheries and tourism.[42] Plastic takes hundreds to thousands of years to degrade, imposing ruinous costs onto future generations. As awareness of the detrimental impacts of plastic has risen, so has public concern. Plastic pollution is now regularly cited as one of the top three major environmental concerns from the public's perspective globally.[43]

Over the past decade awareness and understanding of the detrimental impacts and potential solutions to the problem have increased significantly. The threat of marine plastic pollution first emerged in the 1970s with reports of plastic pellets in the North Atlantic and was later cemented by the discovery of the Great Pacific Garbage Patch in 1997.[44] Concerns about the negative impacts of plastic across its lifecycle and the more recent focus on microplastics has led to growing research into the negative impacts of plastic. Findings to date have uncovered that across its lifecycle, plastic impacts marine species, terrestrial environments, and potentially even human health and contributes to the climate crisis. As the negative impacts of plastic have emerged, increasing efforts are being made to tackle the plastic crisis through national regulations and other measures including voluntary initiatives such as WWF's ReSource: Plastics and the New Plastics Economy Global Commitment. However, despite these best efforts, there has also been increased recognition of the limitations of currently fragmented international frameworks.[45] Consensus is growing around the need for global, coordinated, and systemic action.

This report aims to build on the valuable work that has been done to date and offer a consolidated view on the negative impacts of the plastic lifecycle and the associated minimum lifetime cost of plastic. This report will demonstrate how the minimum lifetime cost of plastic is far above the market price and how society is subsidising a broken plastic system. It also outlines why a global treaty is the rational next step in global policy to tackle the plastic crisis, explaining how the treaty will address the negative impacts and help to account for the costs of the plastic lifecycle.

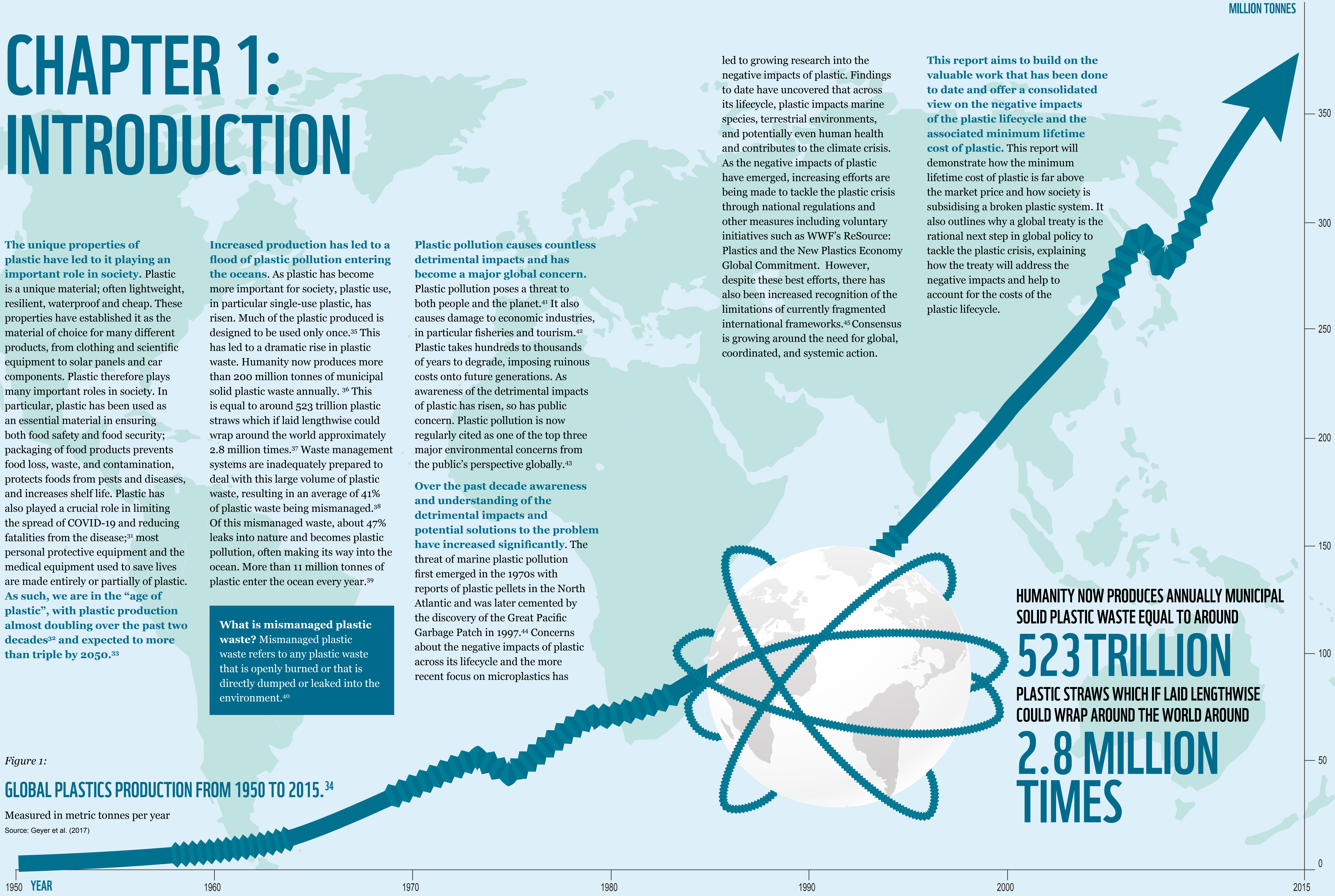


Figure 1:

GLOBAL PLASTICS PRODUCTION FROM 1950 TO 2015.[34]

Measured in metric tonnes per year

Source: Geyer et al. (2017)

CHAPTER 2: THE PROBLEM

SOCIETY AND GOVERNMENTS ARE UNKNOWINGLY BURYING THEMSELVES IN INCREASING PLASTIC DEBT

INTRODUCTION TO THE LIFETIME COST OF PLASTIC

The lifecycle of plastic does not end when it is thrown away, but extends far beyond this point, potentially for thousands of years (*see Figure 2*):

Across this lifecycle, the negative impacts of plastic impose costs on governments and societies that are far greater than the market cost of plastic. Some of these negative impacts such as waste management, impose direct economic costs, while others impose indirect costs, placing a burden on societies and governments by impacting the environment and human health. The durability of plastic, while beneficial for many of its uses, means that these costs will be incurred for long time periods. Plastic takes hundreds to thousands of years to fully degrade and as it degrades, it breaks down into smaller and smaller particles.[46,47] This makes plastic hard to recover and remove once it has entered the environment. This sets the plastic crisis apart from other materials that also impose costs not included in their price, as they either degrade quicker (for example, paper) or are easier to recover.

Costs induced by plastic not accounted for in the market price, include:

- The cost of GHG emissions
- Health costs
- Waste management costs
- Mismanaged waste costs *(see Figure 3)*.

While the links between the plastic lifecycle and these externalities are well known, in some cases a lack of data limits understanding of the extent of those impacts. Within each cost dimension there are some elements that are quantifiable and some that currently aren't *(see Table 1)*.

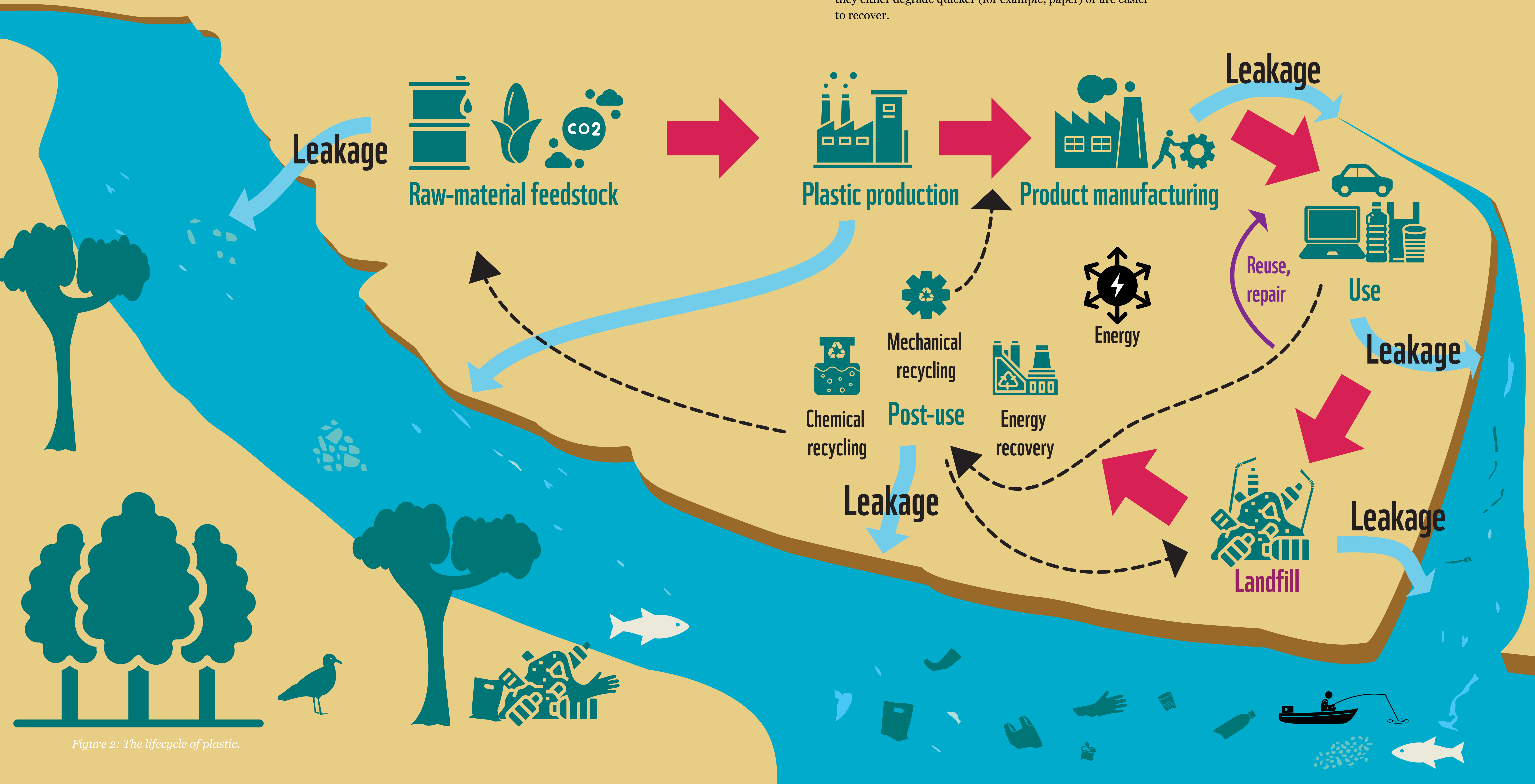


Figure 2: The lifecycle of plastic.

Figure 3: Overview of the costs included in the minimum lifetime cost of the plastic produced in 2019.

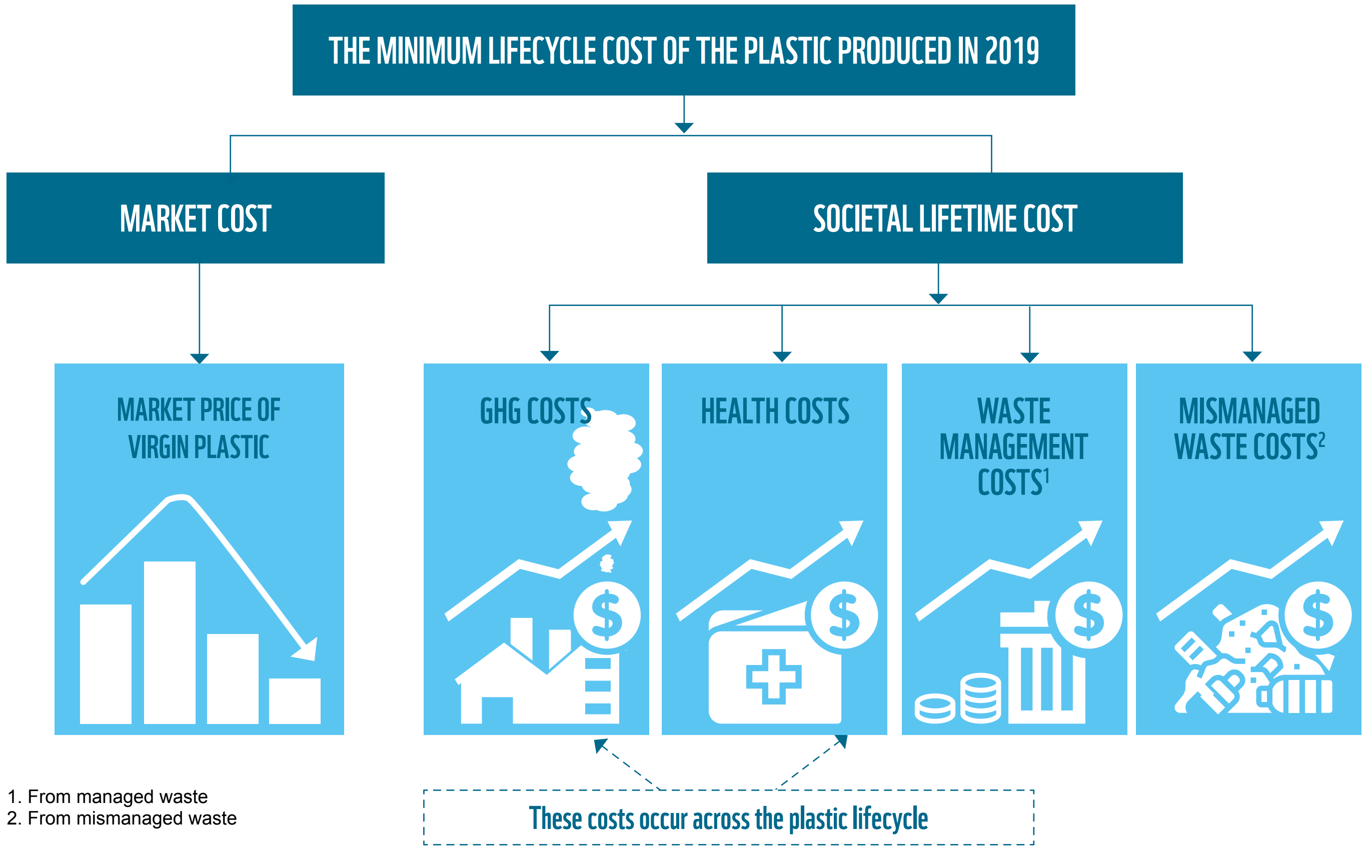


Table 1: Overview of the quantifiable and currently unquantified costs imposed by the plastic lifecycle.

Cost Dimension	Quantifiable Elements	Currently Unquantified Elements
Market Cost	Market price of virgin plastics	
GHG emissions	• Costs of GHG emissions from production processes • Costs of GHG emissions from waste management processes Both paid for indirectly by society (based on carbon prices and costs to stick to carbon commitments)	• Costs of GHG emissions from uncontrolled plastic waste
Health		• Health costs from production processes • Health costs from waste management processes • Health risks from plastic use • Health costs of uncontrolled plastic waste
Waste management	• Direct costs to governments and indirectly to corporates or citizens based on the taxes used to fund it or EPR schemes in place for formal waste management. • Costs to informal waste management sector to conduct informal waste management activities.	
Unmanaged waste	• Lost ecosystem service costs of marine plastic pollution paid for indirectly by governments and all other stakeholders, given the environmental and economic consequences • Revenue reductions from fisheries and tourism as a result of marine plastic pollution • Clean-up activity costs	• Lost ecosystem service costs of plastic pollution on terrestrial ecosystems (any ecosystems which are found on land including rainforests, deserts, and grasslands)

The first part of this chapter provides an estimate of what is considered the minimum cost societies, corporates and governments will have to pay because of the plastic lifecycle. In this section, only components for which there is sufficient research to be able to quantify the costs are included.

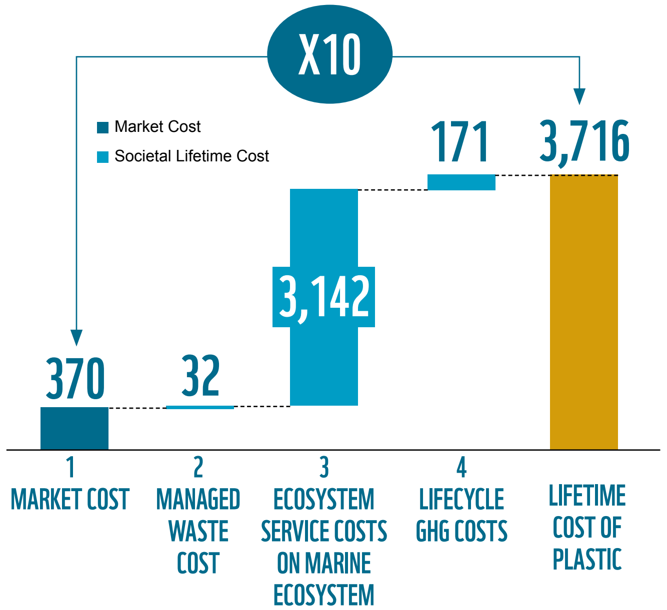
The second part of this chapter shares perspectives on additional costs that are not integrated into the cost estimate as research is still in progress. However, the presence of these costs means that the burden countries bear from the plastic lifecycle is even higher than the current cost estimate suggests.

The third part of this chapter provides projections for how these costs could grow under a business as usual (BAU) scenario.

PLASTIC'S MARKET PRICE MAKES IT A RELATIVELY CHEAP COMMODITY, BUT THE ACTUAL COST INCURRED OVER THE PLASTIC LIFECYCLE IS AT LEAST TEN TIMES HIGHER – FOR EXAMPLE, US$3.7 TRILLION (+/-US$1 TRILLION) FOR JUST THE PLASTICS PRODUCED IN 2019. *(see Figure 4)*

The minimum cost that the plastic produced in 2019 will incur over its lifetime is estimated at US$3.7 trillion (+/-US$1 trillion),[48] with more than 90% of that cost not included in the market price of plastics. This includes the cost of GHG emissions and waste management costs, which society, corporates and citizens have to pay. The lifetime cost of plastic is a huge burden on society. The lifetime cost of the plastic produced in 2019 is more than India's GDP (*See Figure 5*).[49]

Figure 4: The lifetime cost of plastic produced in 2019 is ten times greater than the market cost



Note: Numbers in the figure are rounded to the nearest billion.

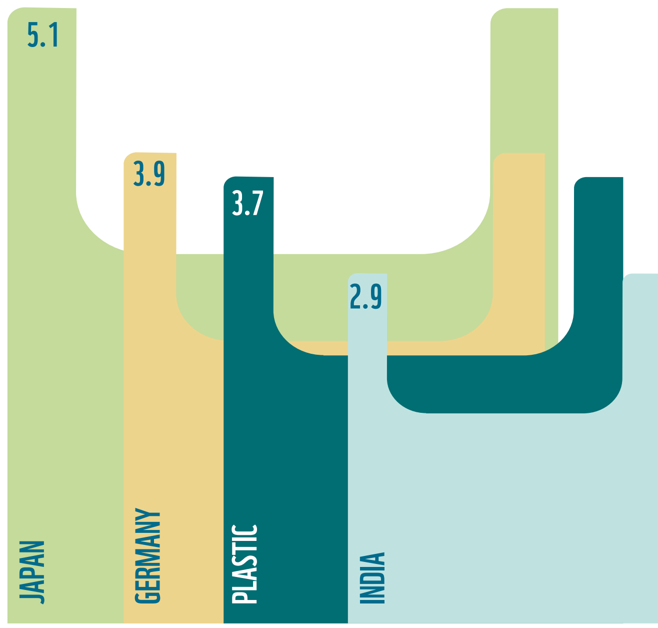
The market cost of plastic produced in 2019 is approximately US$370 billion based on the price primary plastic producers paid for virgin plastic.[51,52] 90% of plastic produced uses virgin fossil fuel feedstocks,[52] which means the price of plastic is directly linked to the cost of oil and gas. Large subsidies for the fossil fuel industry have contributed to the relatively cheap price of virgin plastic. Therefore, when only considering its market price, plastic can appear to be a relatively cheap commodity.

Across the lifecycle, plastic is a significant emitter of GHG, with the emissions resulting from the plastic produced in 2019 imposing a cost of more than

> **What is virgin plastic?** Virgin plastic is the direct output produced from refining a petrochemical feedstock, such as natural gas or crude oil, which has never been used or processed before.

US$171 billion, equivalent to more than a third of spending on energy transitions globally in 2020.[53] Across its lifecycle, plastic is responsible for generating 1.8 billion tonnes of GHG emissions a year[54] *(see Deep Dive 1)*. That is more than the annual emissions from aviation and shipping combined.[55] If plastic were a country, it would be the fifth-highest GHG emitter in the world.[56] These GHG emissions are accelerating the surge of climate-change related negative impacts such as shrinking glaciers,[57] flooding,[58] and crop death from more intense droughts,[59] imposing huge costs on governments and society. These already significant costs are only a beginning, as research indicates that the economic cost of climate change will only increase.[60]

Figure 5: The lifetime cost of the plastic produced in 2019 is more than India's GDP (US$ trillion).[50]



© shutterstock / Gorlov-KV

DEEP DIVE 1: PLASTIC EMITS SIGNIFICANT GHG EMISSIONS AT EVERY STAGE OF THE LIFECYCLE:

Research has shown that 91% of the GHG emissions from plastic came from plastic production processes,[61] meaning that plastic imposes significant costs on society before it even becomes waste. The majority of GHG emissions are emitted before use by consumers, during the extraction and manufacturing stages of the plastic lifecycle, estimated at 1.6 gigatons in 2015.[62] However, early-stage research suggests that the GHG contribution from when plastic becomes waste could be much higher than current estimates suggest.[63]

Waste management also produces GHG emissions, including both direct and indirect contributions made by incineration and landfill. The end-of-life (EOL) stage has previously been estimated to emit lower emissions than other lifecycle stages, at up to 161 million tonnes in 2015.[64] Incineration is the most dominant source of emissions from the EOL stage. Additionally, both landfill and incineration result in a need for new virgin plastic production, contributing to future GHG emissions.

Downstream GHG emissions could also be more significant than initially realised due to emissions from mismanaged plastic waste. Mismanaged plastic waste is either disposed of by burning in open fires or dumping into the landscape, leaking into the environment and often into the ocean. Open burning has severe negative impacts on the climate, as the waste is burned without the presence of air pollution controls. Open burning of waste releases an air pollutant called black carbon, which has a global warming potential up to 5,000 times greater than carbon dioxide.[65] Plastic that is dumped into the landscape also contributes to GHG emissions. As it degrades, plastic continually releases emissions and evidence shows these emissions increase as the plastic breaks down further.[66] Research is still in the early stages, but evidence shows that both marine and terrestrial plastic pollution are a source of GHG emissions, with terrestrial pollution releasing GHG emissions at a higher rate. Therefore, mismanaged plastic is likely a considerable source of GHG emissions. However, due to the limitations of data, this is not included in the minimum lifecycle cost estimate at this stage. The estimate of the cost of GHG emissions from the plastic lifecycle is therefore a lower bound.

Managing plastic waste costs US$32 billion.[67] This encompasses the cost to collect, sort, recycle and/or dispose of the waste by both the formal and informal sector. Municipal solid plastic waste management activities are conducted across the world by both the formal and informal waste sectors.[68] Formal waste management is overseen by the formal solid-waste authorities of a country. Part of the formal costs in some countries are covered by funds raised through EPR systems, where producers pay some of the costs of managing their plastic packaging once it becomes waste. However, in most countries around the world, formal waste management is subsidised by the state with public funds that could otherwise be diverted to education or health. This can result in significant government costs. Formal collection for municipal solid plastic waste alone cost an estimated US$27 billion globally in 2016.[69] The informal waste sector, on the other hand, comprises waste management activities conducted by individuals or enterprises that are involved in private-sector waste-management independent of the formal solid waste authorities.

DEEP DIVE 2: A SELECTION OF DEVELOPING COUNTRIES BEAR A DISPROPORTIONATE SHARE OF WASTE MANAGEMENT COSTS; IN SOME CASES, HIGH-INCOME COUNTRIES (HICS) ARE STILL SHIPPING PLASTIC WASTE TO LOW-INCOME COUNTRIES (LICS) DESPITE ACTIONS BEING TAKEN TO LIMIT THESE PLASTIC EXPORTS.

To benefit from the lower cost of recycling, HICs have historically sent a significant amount of plastic waste overseas to be recycled. Between 1992 and 2018, China cumulatively imported 45% of the world's plastic waste, making the global plastic waste market dependent on access to the Chinese recycling sector.[70] However, in 2018 China passed the National Sword policy limiting plastic waste imports. Due to a lack of recycling capacity, instead of handling the waste that would have been sent to China domestically, HICs turned to countries in South East Asia and Africa. In 2019, the US sent 83,000 tonnes of plastic recycling to Viet Nam alone,[71] equivalent to the plastic waste produced annually by approximately 300,000 US households.[72]

However, a large majority of this waste is not recycled, leaking into environment, and causing damage to destination country environment and human health. Many of the destination countries have limited waste management systems, for example in Viet Nam 72% of plastic waste is mismanaged and becomes plastic pollution.[73] Such plastic pollution imposes countless detrimental impacts on destination countries, including contaminated water supplies, crop death, and respiratory illness from exposure to burning plastic.[74]

Despite policies to tackle plastic exports, limitations in HIC waste management systems necessitate a maintained reliance on exporting waste. Governments have taken action to limit the flow of waste from abroad through the recent amendments to the Basel Convention, but plastic exports are still happening. Trade data for January 2021 showed that American exports of plastic scrap to LICs had stayed at a similar level between January 2020 and January 2021. For example, Malaysia remained a major destination for American scrap plastic in January 2021.[75]

Illegal waste operations have also emerged, taking advantage of the lack of capacity in formal systems. For example, in emerging Asian importing countries, illegal recycling facilities have profited by circumventing licence costs and environmentally sound treatment costs.[76] The increase in plastic waste has also increased illegal landfills, contributing to the risk of environmental plastic leakage. Therefore, destination country governments are having to pay the cost of the clean-up, enforcement, and monitoring instead of the industries and countries creating the waste.

© shutterstock / Parilov

Plastic produced in 2019 will impose a cost of more than US$3.1 trillion (+/-US$1 trillion) over its lifetime in the form of a reduction in marine ecosystem services, 85% of this cost will be borne by societies and governments in the next 100 years.[77]

The ocean is one of the world's most important resources fulfilling a range of roles for people, known as ecosystem services.[78] Annual ecosystem services provided by marine ecosystems are estimated to be worth US$61.3 trillion in 2011,[79] the key components being provisioning, regulating, habitat and cultural services.[80] Provisioning services include the various goods people can obtain from marine habitats, including aquatic food in the form of farmed or wild capture fish, invertebrates, and seaweeds. Regulating services include carbon sequestration (*see Deep Dive 3),* flood control, and pest control. Finally, habitat and cultural services include novel chemicals, genetic diversity, spiritual sites, and recreation.

Plastic waste reduces the value that people can derive from the ocean. While available research does not yet allow us to accurately quantify the decline in annual ecosystem service delivery related to marine plastic, evidence suggests substantial negative impacts on almost all ecosystem services on a global scale.[81] Additional research is needed to precisely quantify this reduction, but it is considered conservative by marine ecosystem experts to assume that the reduction of marine ecosystem services because of marine plastic pollution is likely to be between 1-5%.[82] This would bring the minimum cost of plastic pollution to US$4,085-8,170 per tonne of plastic in the ocean per year.[83] This estimate is conservative when compared to the reduction in terrestrial ecosystem services due to anthropogenic disturbances available in the literature.[84] Plastic will continue to incur costs every year as it breaks down into smaller particles, this means that each tonne of plastic that enters the ocean incurs a minimum of US$204,270-408,541 over its lifetime.[85] Therefore, the plastic produced in 2019 that becomes marine plastic pollution will incur a minimum cost of US$3.1 trillion (+/-US$1 trillion) over its lifetime in the ocean, equal to more than 60% of global spending on education in 2019.[86]

DEEP DIVE 3: MISMANAGED PLASTIC WASTE COULD THREATEN THE ABILITY OF THE OCEANS TO ACT AS A CARBON SINK, FURTHER CONTRIBUTING TO THE CLIMATE CRISIS.

The ocean is one of the world's largest carbon sinks. The ocean plays a critical role in removing carbon dioxide (CO_2) from the atmosphere, absorbing more than 25% of all CO_2 emissions.[87] Biological processes occurring in the ocean capture carbon from the ocean's surface and transport it to the seabed, removing it from the atmosphere. For example, phytoplankton ingest carbon during photosynthesis. Zooplankton and other marine organisms then consume the phytoplankton and release the captured carbon in their faecal matter. This excreted carbon then sinks to the ocean floor where it remains trapped for hundreds to thousands of years.[88]

Plastic may be limiting the effectiveness of the ocean as a carbon sink. Both lab and field experiments have confirmed that microplastics are being ingested by zooplankton.[89] This ingestion can make zooplankton faecal matter more buoyant, meaning it is slower to sink to the ocean floor.[90] Lab experiments have also shown that microplastic ingestion can impact on the feeding rate of zooplankton. For example, exposure to polystyrene beads resulted in ingestion of 11% fewer algal cells and 40% less carbon biomass, with a reduction in the size of algae consumed.[91] Exposure to microplastics could therefore have negative impacts on zooplankton growth and reproduction.[92] These two impacts have potential implications for the functioning of the ocean as a carbon sink. For instance, the slower zooplankton sinks, the more time carbon has to escape back into the atmosphere.

Additionally, given the importance of zooplankton to the functioning of the sink, threats to zooplankton populations from reduced feeding could also interfere with the sink. Research into these impacts is nascent. Nonetheless, the emerging evidence highlights that plastic threatens the carbon sink function of the ocean.

Plastic could therefore be contributing to the climate crisis on two fronts, by emitting CO_2 and by limiting the ability of the ocean to remove this CO_2, exacerbating the impact of the emissions.

© shutterstock / Fedorova Nataliia

Marine plastic pollution can also create huge economic costs in the form of GDP reductions, estimated at up to US$7 billion for 2018 alone.[93] The presence of plastic pollution on coastlines can deter visitors from tourist hotspots.[94] This can result in a reduction in revenues for the tourism industry as visitor numbers fall, particularly when plastic litter is present during the peak tourist season. Marine plastic pollution also puts fishing and aquaculture activities at significant risk. Marine plastic pollution may contaminate aquaculture, reducing the quality of farmed fish and making it non-marketable.[95] Additionally, the presence of plastic in the ocean can reduce water quality, affecting fish larvae survival.[96] This can reduce fish catch in a given year, impacting revenues for fisheries and aquaculture. For example, the combined reduction in revenue from tourism and fisheries has been estimated at between US$0.5 and US$6.7 billion per year for 87 coastal countries.[97] This estimate is not included in the high-level estimate to avoid double-counting as the impact on fisheries and tourism is already accounted for in the figure that estimates the cost of marine ecosystem service reduction.

Governments, non-governmental organizations (NGOs) and concerned citizens also incur significant costs from undertaking clean-up activities to remove the waste, as high as US$15 billion per year.[98] Most of these clean-up activities are focused on inhabited coastline, rivers, ports, and marinas, although *ad hoc* activities are also conducted in terrestrial environments. There are direct costs in the form of government and NGO funding for transport and employee time. At the same time, there are also indirect costs in the form of the time spent by unpaid volunteers, and potential health risks from clearing sometimes sharp and hazardous plastic waste. The direct cost of these activities can be high; it is estimated that if the floating plastic waste in rivers, ports and marinas had been collected and plastic cleared from beaches across 87 coastal countries in 2018, it would have cost US$5.6-15 billion.[99] While they weigh financially on governments and NGOs, clean-up costs are not included in the quantification developed in this report, to avoid any double counting between these costs and the costs of plastic waste pollution.

SPOTLIGHT: GHOST GEAR IS THE MOST DAMAGING FORM OF MARINE PLASTIC.

Between 500,000 and 1 million tonnes of abandoned or lost fishing gear are entering the ocean every year.[100] This "ghost gear" poses significant threats to marine wildlife, habitats, and even the livelihoods of coastal communities:

Ghost gear is responsible for thousands of marine animal deaths a year. Marine debris affects approximately 700 species living in the world's oceans, with animals often getting tangled and trapped in nets,[101] as seen in Australia (*see Annex 1: Country Deep Dives*). This can prove fatal; 80% of entanglement cases result in direct harm or death to the animals involved. A previous WWF report highlighted that ghost gear is responsible for harming two-thirds of marine mammal species, half of seabird species, and all species of sea turtles.[102] A recent study of a haul-out site[103] in southwest England witnessed 15 seals entangled over a year, of which 60% had entangling material cutting through their skin causing wounds considered to be serious, and two additional entangled seals died during the study period.[104] Animals that become entangled can be left to suffer for several months or even years subjecting them to a slow, painful and inhumane death.[105] This can pose significant threats to endangered species; in the northeastern Mediterranean, entanglement of endangered monk seals with fishing gear was cited as the second most frequent cause of death after deliberate killing.[106]

Ghost gear also damages vital marine habitats, posing serious threats to the health of the ocean. Marine habitats such as coral reefs and mangroves are important for the functioning of marine ecosystems, serving as breeding grounds or nurseries for nearly all marine species.[107] Ghost gear can entangle parts of the coral reef, breaking parts off and causing coral fractures, impacting the reef ecosystem.[108] This damage could have potentially devastating consequences, with habitat destruction being closely linked to biodiversity loss.[109]

Ghost gear threatens the food sources and livelihoods of coastal communities. Threats to biodiversity and reductions in marine resources from plastic pollution can threaten the livelihoods of coastal communities. Communities that rely on fishing for income will also face safety risks because of the navigation hazards posed by ghost gear.[110] Entanglement of a fishing vessel can affect the vessel's stability in the water and restrict its ability to manoeuvre, putting it at risk of capsize or collision.[111] An extreme example of the potential risk was seen in South Korea in 1993, when a passenger ferry became entangled in a nylon rope causing the vessel to turn, capsize and sink resulting in 292 deaths.[112]

© naturepl.com/ Enrique Lopez-Tapia/ WWF

BEYOND THE COSTS THAT ARE CURRENTLY QUANTIFIABLE, THERE ARE ADDITIONAL NEGATIVE CONSEQUENCES OF PLASTIC PRODUCTION, CONSUMPTION AND DISPOSAL THAT ARE NOT YET FULLY UNDERSTOOD.

The currently quantifiable lifecycle cost of plastic is significant, but this could be just the tip of the iceberg. Data and research gaps and limitations in estimation techniques restrict the quantification of all of the negative impacts of plastic. Therefore, there are many known unknowns associated with the plastic lifecycle. This section focuses on a limited subset to outline the problem.

The production, incineration, and open burning of plastic polymers releases chemical pollutants that pose a significant threat to human health.

Plastic production processes release chemical pollutants, putting populations at risk of negative health impacts. The extraction of oil and gas for plastic production releases countless toxic substances into the air and water, often in significant volumes.[113] Over 170 fracking chemicals used to produce the main feedstocks for plastic are known to cause human health problems, including cancer and neurotoxicity.[114] Studies have found that higher concentrations of fracking wells are associated with higher inpatient hospitalisation for cardiac or neurological problems.[115] Transforming fossil fuels into plastic resins also releases carcinogenic and other pollutants with documented negative impacts on the nervous and reproductive systems, among other adverse health impacts.[116]

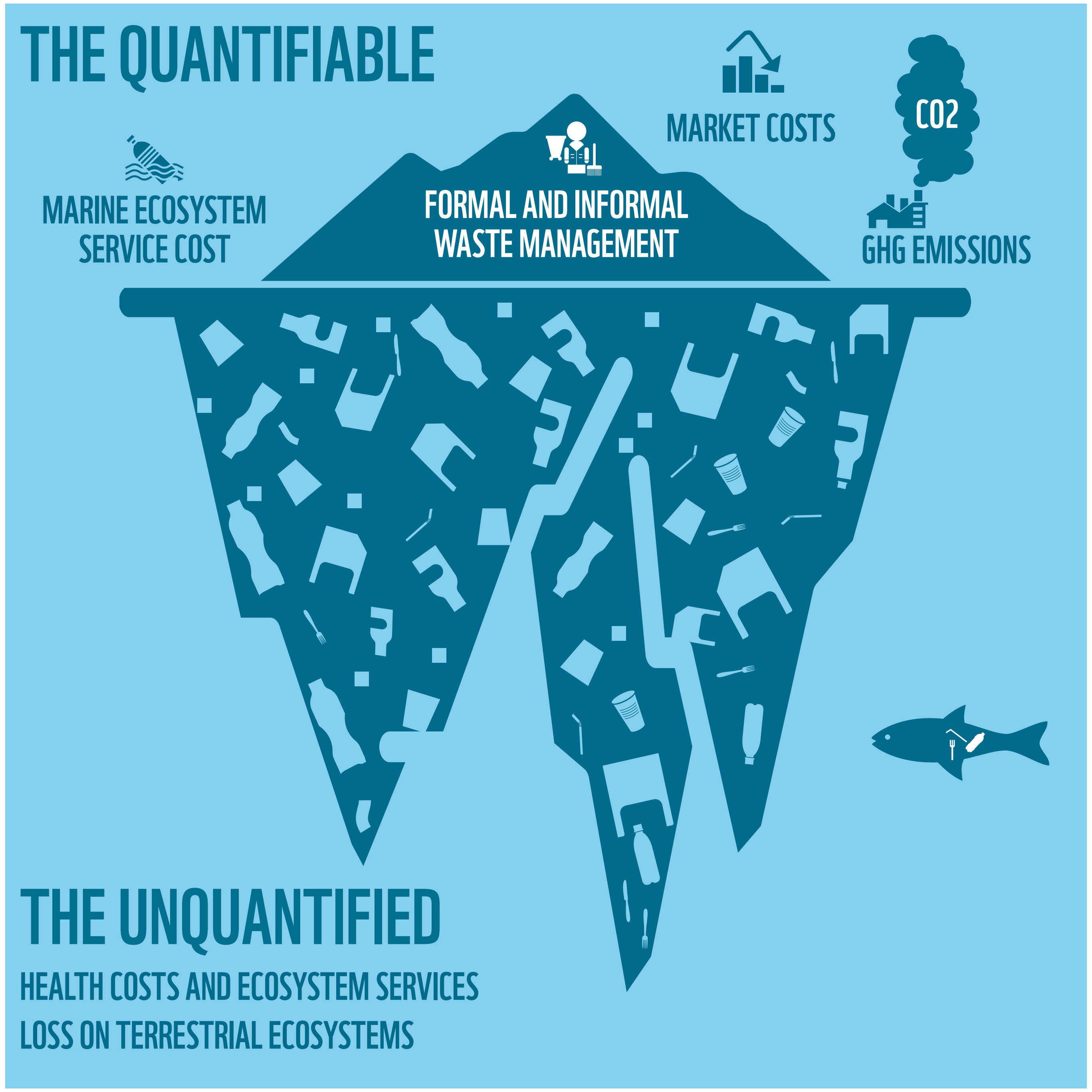
Incineration of plastic, particularly with inadequate emission standards or uncontrolled burning, releases harmful substances which can travel long distances.[117] These substances are linked to adverse human health impacts including respiratory problems, cancers, and neurological damage.[118] For example, dioxins and related compounds are formed when one of the most widely produced synthetic plastic polymer polyvinyl chloride (PVC) is burned in open fires. At least 30 of these compounds are considered harmful to human health, with evidence that they can damage the brain and disrupt hormones.[119] The toxins from incineration and open burning can travel long distances and persist in the environment for many years. Humans then ingest these substances via plants and animals that have accumulated them.[120]

Plastic production, incineration, and open burning can pose significant threats to human health. However, the extent to which these threats are being realised in the population is still largely undocumented.

Evidence of human exposure to microplastics is growing, but scientific understanding of the health implications is still limited.

Humans face exposure to microplastics in all aspects of daily life. It is in the air people breathe, the water they drink, the food they eat, and the clothes they wear. In particular, microplastic fragments have been detected in tap and bottled water, honey, shrimps, and salt among other human consumption products.[121,122,123] Scientific research has also found the presence of microplastic particles in human faeces.[124] This suggests that humans are inadvertently ingesting plastic. Furthermore, microplastics have even been detected in placentas, suggesting the inadvertent ingestion of microplastics by mothers can expose unborn children to microplastics.[125]

However, the link between microplastic ingestion and negative human health impacts remains a source of uncertainty. Due to ethical concerns preventing studies that expose humans to microplastics to study the health impacts, initial studies have focused on evaluating the impact of microplastics on marine species and small mammals.[126] One study of mice reported that microplastics may induce changes in energy and fat metabolism and cause disruption to the functioning of the nervous system, with potential implications for human health. Although, current evidence suggests that the majority of plastic particles are expected to pass through the gastrointestinal tract without being absorbed,[127] it has been hypothesised that once ingested, microplastics could release harmful chemicals that were ingredients of the initial plastic product or pathogenic contaminants that the plastic particles have absorbed while in the environment.[128] As this is a relatively new area of research, the World Health Organization have so far stated that there is not enough evidence to conclude that microplastic particles pose a threat to human health.[129]



Plastic pollution also poses potential risks to terrestrial ecosystems, but this remains largely unresearched. Despite a growing body of research on the effect of plastic pollution on marine ecosystems, the potential impacts on terrestrial ecosystems remain largely unexplored. A 2019 literature review on the effects of plastic pollution found that 76% of studies were relevant to marine ecosystems while only 4% were relevant to terrestrial ecosystems.[130] However, the research that does exist outlines the material threat that plastic poses:

Terrestrial organisms face multiple exposure points to plastic. Plastic ingestion has been reported in terrestrial birds,[131] as well as sheep and goats.[132] It has also been reported that bees incorporate anthropogenic debris like plastic into their nests.[133] Increased usage of plastic in agricultural practices has also led to an increase in the presence of plastic debris in agricultural soils.[134]

These interactions could pose threats both to the lifespan of these organisms and some key ecosystem processes. For example, plastic beads of a similar size to pollen could potentially disrupt important plant and pollinator ecological functions.[135] It is also clear that plastic has the potential to entangle and suffocate land animals, threatening terrestrial wildlife. Chemical effects of plastic, although less discussed, could also prove damaging for terrestrial ecosystems. Microplastics can stunt earthworm growth and cause them to lose weight which, due to their importance for soil health, could have detrimental impacts on soil ecosystems and even plant growth.[136] Additionally, the accumulation of plastic in soils themselves can lead to potentially irreversible soil degradation.[137] Therefore, some species and ecological processes may already be under significant pressure from exposure to plastics, threatening the functioning of terrestrial ecosystems.


West Bengal, India © Alamy Stock Photo

SPOTLIGHT: THE ENVIRONMENTAL INJUSTICE OF THE PLASTIC LIFECYCLE

Marginalised communities disproportionately bear the cost of the plastic lifecycle:

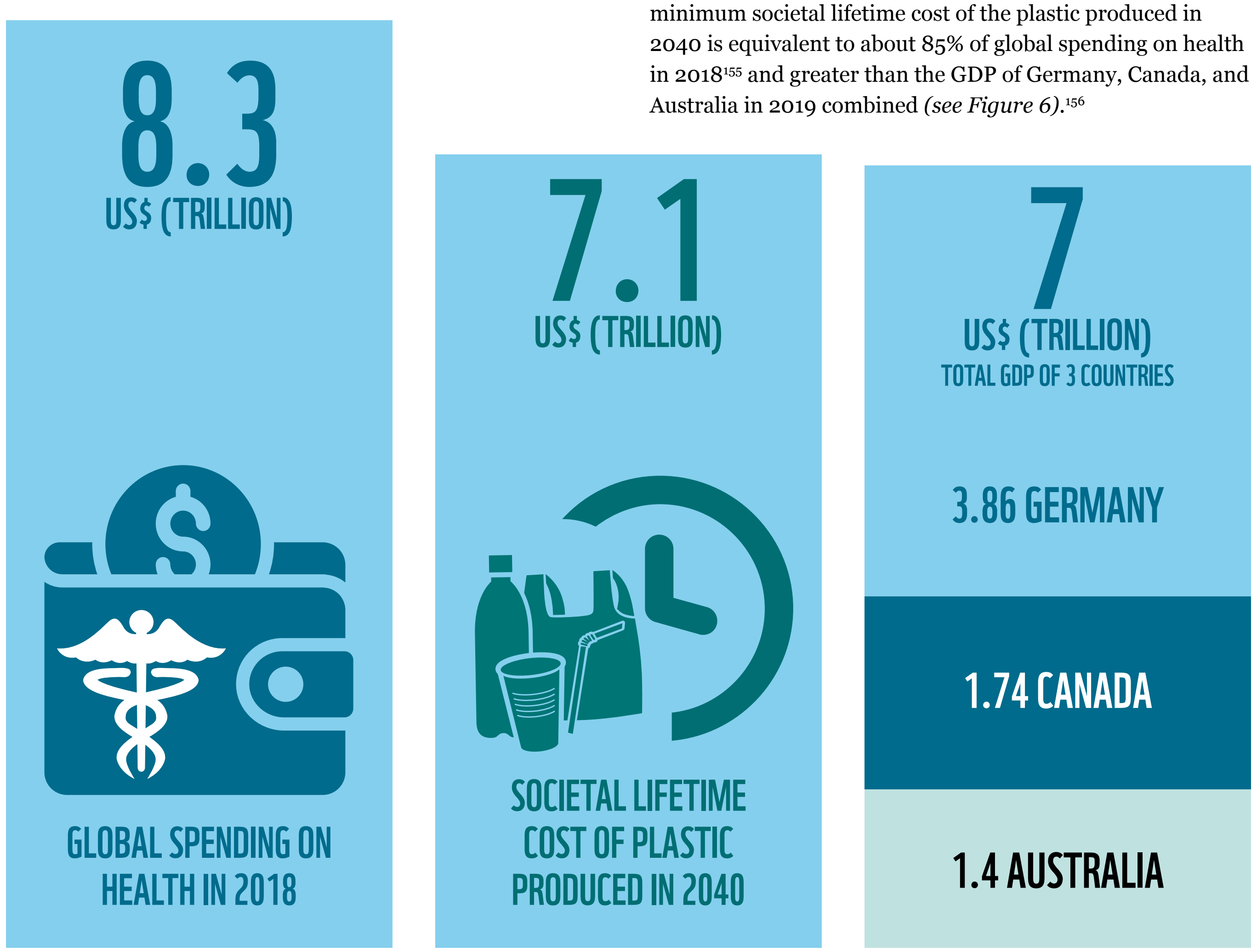
Incineration plants and oil and gas refineries are built predominantly in low-income and marginalised communities exposing them to health and economic risks. Research in 2019 found that of the 73 incinerators across the US, 79% are located within three miles of low-income and minority neighbourhoods.[138] Furthermore, additional research found that incinerators and landfills are disproportionately sited in indigenous communities because their lands have unclear tenure status.[139] Crude oil and gas refineries are also disproportionately built in low-income and marginalised communities.[140] This exposes these communities to chemical pollutants which are released during the incineration and refining processes. Communities are often also given inadequate access to information regarding the risks they are exposed to, limiting their ability to protect themselves.[141] Not only do these neighbourhoods face health risks, but they also face negative economic impacts as the presence of plants reduces house prices. A study focused on incineration plants in China, found that neighbouring properties show decreases in the initial listing price of up to 25%.[142]

Informal waste pickers are exposed to significant health risks throughout the plastic waste processing cycle. Prolonged and frequent exposure to faecal matter, medical waste, and hazardous substances puts informal waste pickers at risk of chronic health conditions such as respiratory disorders.[143] Waste pickers also often lack protective clothing and equipment, despite being directly exposed to toxic waste. An assessment of the evidence of negative health impacts from open burning of plastic waste indicated a high risk of harm to waste pickers.[144] Documented impacts include epidermal issues, communicable diseases, musculoskeletal issues, respiratory diseases, non-communicable diseases, gastrointestinal issues, and waterborne diseases.[145] Informal waste pickers also often face barriers to accessing adequate healthcare to help treat occupational-related health conditions. For example, a study in South Africa found that less than half of informal waste pickers had used a healthcare facility in the previous 12 months, citing the inability to take time off work as a significant barrier to health-care utilisation.[146]

Climate change, which the plastics lifecycle is already contributing to, disproportionately affects disadvantaged groups. Studies have concluded that rising temperatures caused by climate change will have unequal effects across the world, with most of the consequences borne by those who are least able to afford it. Empirical evidence suggests that countries with better-regulated capital markets, higher availability of infrastructure, flexible exchange rates, and more democratic institutions are likely to recover faster from the negative impacts of temperature shocks.[147] Furthermore, in hot regions of emerging and developing countries, higher temperatures are shown to constrain growth more than in hot regions of developed countries. Therefore, in low-income countries, the adverse effect is long-lasting and is the result of various negative impacts including lower agricultural output, poorer human health, and depressed labour productivity in sectors more exposed to the weather. As such, developing and emerging economies will likely suffer disproportionately from the consequences of global warming and adverse weather events caused by climate change.[148] Additionally, within these countries, adverse effects are likely to be felt by the most disadvantaged groups. Available evidence indicates that the relationship between climate change and socio-economic inequality can be characterised as a vicious cycle.[149] Initial inequalities cause disadvantaged groups to suffer disproportionately from the adverse effects of climate change, with these negative impacts then resulting in greater subsequent inequality.

The plastic lifecycle imposes significant costs and risks that are not accounted for in the price of plastic. The plastic produced in 2019 will impose a cost of more than US$3.7 trillion (+/-US$1 trillion) over its lifetime that society and governments have already started to pay.[150] More than 90% of the lifetime cost of the plastic produced in 2019 is currently not accounted for in the market price of plastic. On top of that, the currently unquantified risks are also not included in the market price meaning the cost borne by society is likely even larger than the current quantifiable estimate suggests. Therefore, governments and citizens are currently unknowingly subsidising a plastic system that is imposing countless negative impacts and creating environmental injustice.

Figure 6: The societal lifetime cost of the plastic produced in 2040 is equivalent to 85% of global spending on health in 2018.[157] and greater than the GDP of Germany, Canada and Australia in 2019 combined. greater than the GDP of Germany, Canada and Australia in 2019 combined.[158]



WITHOUT SIGNIFICANT ACTION THE COSTS AND NEGATIVE IMPACTS IMPOSED BY THE PLASTIC LIFECYCLE WILL CONTINUE TO RISE, THE SOCIETAL LIFETIME COST OF THE PLASTIC PROJECTED TO BE PRODUCED IN 2040 COULD REACH US$7.1TRILLION (+/-US$2.2 TRILLION)

Plastic production and pollution are predicted to significantly increase over the coming decades. Plastic production is expected to more than double by 2040.[151] Under BAU, it is also estimated that there will be a tripling of pollution entering the ocean to 29 million tonnes,[152] increasing the total stock of plastic in the oceans to 600 million tonnes. This is equivalent to around double the weight of the entire global adult population in 2005.[153]

Therefore, under BAU, the minimum societal lifetime cost of the plastic produced in ten years will increase to US$5.2 trillion (+/-US$1.6 trillion), while the societal lifetime cost of the plastic produced in 2040 will increase to US$7.1 trillion (+/-US$2.2 trillion).[154] This is a huge potential cost for governments and society that could be diverted to public spending on other important issues, for example, health. The projected minimum societal lifetime cost of the plastic produced in 2040 is equivalent to about 85% of global spending on health in 2018[155] and greater than the GDP of Germany, Canada, and Australia in 2019 combined *(see Figure 6)*.[156]

Under BAU, emissions from the plastic sector alone would use up to 20% of the entire global carbon budget,[159] undermining government actions to tackle the climate crisis.[160] By 2040, emissions from plastic are estimated to increase to 2.1 billion tonnes of CO_2e per year.[161] This is in direct contrast with global goals to limit the warming of the planet to 1.5 C above pre-industrial levels, which necessitates net-zero emissions by 2050.[162] The expected growth in plastic production and corresponding rise in GHG emissions therefore endangers global efforts to tackle the climate crisis, undermining the actions taken by governments across the world. Governments are dedicating portions of their budgets to climate mitigation and adaptation. For example, between 2014 and 2020 the EU dedicated approximately 20% of its annual budget to climate action.[163] Increases in GHG emissions from the plastic lifecycle can limit the effectiveness of this spending or require further spending increases. Furthermore, the later societies and governments take plastic action and reduce the associated GHG emissions, the bigger the price to pay will be.

It is therefore clear that action on plastic is both an important and necessary part of climate action.


Stoke-on-Trent, the UK, 2019
© Alamy Stock Photo

CHAPTER 3: BARRIERS TO ACTION

MANY OF THE NECESSARY SOLUTIONS ARE ALREADY KNOWN, BUT GLOBALLY WE HAVE FAILED TO IMPLEMENT THEM FOR SEVERAL REASONS

Organisations like the Ellen MacArthur Foundation (EMF), World Economic Forum (WEF), and the Pew Charitable Trusts have outlined the necessary lifecycle approach to tackle the plastic crisis. Plastic imposes large costs and risks across the whole lifecycle, which means that efforts need to tackle all stages of the lifecycle. In response to this challenge, there has been a growing focus on systems change towards plastic circularity that considers the complete product lifecycle, including all stages before and after plastic reaches the consumer.[164] This approach aims to keep plastics in the economy and out of the environment by creating a "closed loop" system, rather than a system in which plastic is used once and then discarded. The principles of this approach include:

- **ELIMINATE** the plastics we don't need, not just removing the straws and carrier bags, but rapidly scaling innovative new delivery models that deliver products to customers without packaging or by using reusable packaging.
- Rapidly design all plastic items to be reusable, recyclable or compostable. It is also crucial to fund the necessary infrastructure, rapidly increasing our ability to collect and **CIRCULATE** these items.
- **INNOVATE** at speed and scale towards new business models, product design, materials, technologies and collection systems to accelerate the transition to a circular economy.

A number of comprehensive interventions which can support the transition to a circular economy have already been identified. For example, the Pew Charitable Trusts has proposed nine systemic interventions in line with circular economy principles:[165]

1. Reduce growth in plastic production and consumption
2. Substitute plastic with paper and compostable materials
3. Design products and packaging for recycling
4. Expand waste collection rates in the middle-/low-income countries
5. Double mechanical recycling capacity globally
6. Develop plastic-to-plastic conversion
7. Build facilities to dispose the plastic that cannot be recycled economically
8. Reduce plastic waste exports by 90%
9. Roll out known solutions for four microplastic sources[166]

A circular economy approach has the potential to reduce the costs and tackle the negative impacts of the plastics system. Research has shown that this approach could reduce the annual volume of plastic entering the oceans by 80% and GHG emissions from plastic by 25%,[167] while promoting job creation and better working conditions. By one estimate, a circular economy approach could create 700,000 quality jobs across the plastic value chain by 2040.[168] An increase in plastic material value through design for recycling can also lead to significant improvements in waste pickers' working conditions and earnings.

However, progress on the implementation of these approaches has been slow because of misplaced incentives for both government and industry. The systems overhaul needed to tackle the plastic crisis can be highly costly and complicated, particularly for countries that lack sophisticated waste management systems. A substantial shift of investment is needed away from virgin plastic towards the production of new delivery models, plastic substitutes, recycling facilities, and collection infrastructure.[169] For example, estimated annual funding of around US$30 billion will be needed to fund new infrastructure.[170] However, there is currently no feedback loop from the adverse aspects of the plastic system because the lifecycle cost of plastic is not fully accounted for in the price. Therefore, action can be deterred due to the financial resources required for implementation when, in reality, this cost is likely lower than the cost imposed by the plastic lifecycle. For example, *Breaking the Plastic Wave* highlighted a potential cost saving from switching from BAU to a systems change approach.[171]

A lack of technical capacity and comprehensive research has also held back government policy. Deep technical expertise in solutions across the plastic lifecycle are needed to ensure government policy is conducive to a circular economy transition. Governments are therefore often held back in implementing such approaches due to the need to build up technical capacity and knowledge. Governments also lack the information required to act due to limitations in scientific understanding of the plastic crisis, and geographic gaps in the data. For example, there is currently an incomplete picture of microplastic emissions.[172] This can hinder government decision-making as there is a lack of understanding of where the problem is coming from and therefore where efforts should be focused.

Government efforts so far have mostly been limited to tackling just one stage of the lifecycle or a too narrow scope of plastic products. Many government efforts so far have focused on just one stage of the lifecycle such as improving waste management or banning plastic bags, none of which will work in isolation.[173] For example, in 60% of the countries which have some form of plastic-related legislation, regulations only address single-use plastic bags.[174]

Current government and industry commitments are likely to reduce annual leakage of plastic by only 7% relative to BAU.[175]

An absence of legal enforcement is limiting the effectiveness of efforts. The number of voluntary initiatives to tackle the plastic crisis and plastic pollution have increased massively over the past five years.[176] While these initiatives are steps in the right direction, they alone are insufficient to tackle the problem. A lack of enforcement of rules or consequences for failure to meet targets can lead to failure in implementation. For example, Australia's Voluntary Code of Practice for the Management of Plastic Bags in 2003 failed to achieve the required reductions in plastic bags and increases in recycling rate. Additionally, global initiatives such as The Ocean Plastics Charter, which is signed by 26 governments and aims to achieve better resource efficiency and lifecycle management approaches to plastic, has been limited by a lack of binding rules.[177]

A lack of global coordination is also undermining government efforts. At a national level, banning plastic bags, along with other plastic packaging, is the most used remedy to rein in plastic waste. So far, 115 nations have taken that approach, but in different ways. In France, bags less than 50 microns thick are banned. In Tunisia, bags are banned if they are less than 40 microns thick.[178] These slight differences can create loopholes that enable illegal bags to find their way into market stalls, undermining government regulations. For example, since Kenya passed the world's toughest plastic bag ban in 2017, it has seen illegal bags being smuggled in from neighbouring countries.[179] This lack of consistency in government regulations can also increase the complexity for multinational business operations; companies that operate in multiple countries must comply with hundreds of slightly different regulations on plastic packaging.[180] This indicates a need for global coordination to effectively tackle the plastic crisis.

Tackling the plastic crisis is beyond the ability of any one country and requires a truly global response, but there is currently no global agreement specifically set-up to tackle marine plastic pollution. Plastic is a transboundary issue with international problem drivers, which necessitates a truly global response. Plastic has a global value chain with the extraction of raw materials, conversion into plastic products, consumption and waste management often happening across multiple countries. Plastic pollution is also not constrained by national boundaries, because it migrates via water and air currents and settles at the seafloor. More than 50% of the ocean's area sits beyond national jurisdiction, including the "garbage patches" (large areas of the ocean where plastic litter accumulate).[181] This means that governments are making efforts to tackle the negative impacts and bearing the cost for actions and decisions that have been made in other countries (for example, product design, choice of ingredients etc.). Governments are unable to control these impacts without a global governance structure. A global response is therefore needed to be able to tackle this global problem. However, currently "no global agreement exists to specifically prevent marine plastic litter and microplastics or provide a comprehensive approach to managing the lifecycle of plastic".[182]

Therefore, there is growing consensus that a global framework is needed to fill the gap in the current policies and provide the technical guidance and coordination mechanism required to tackle the plastic crisis.

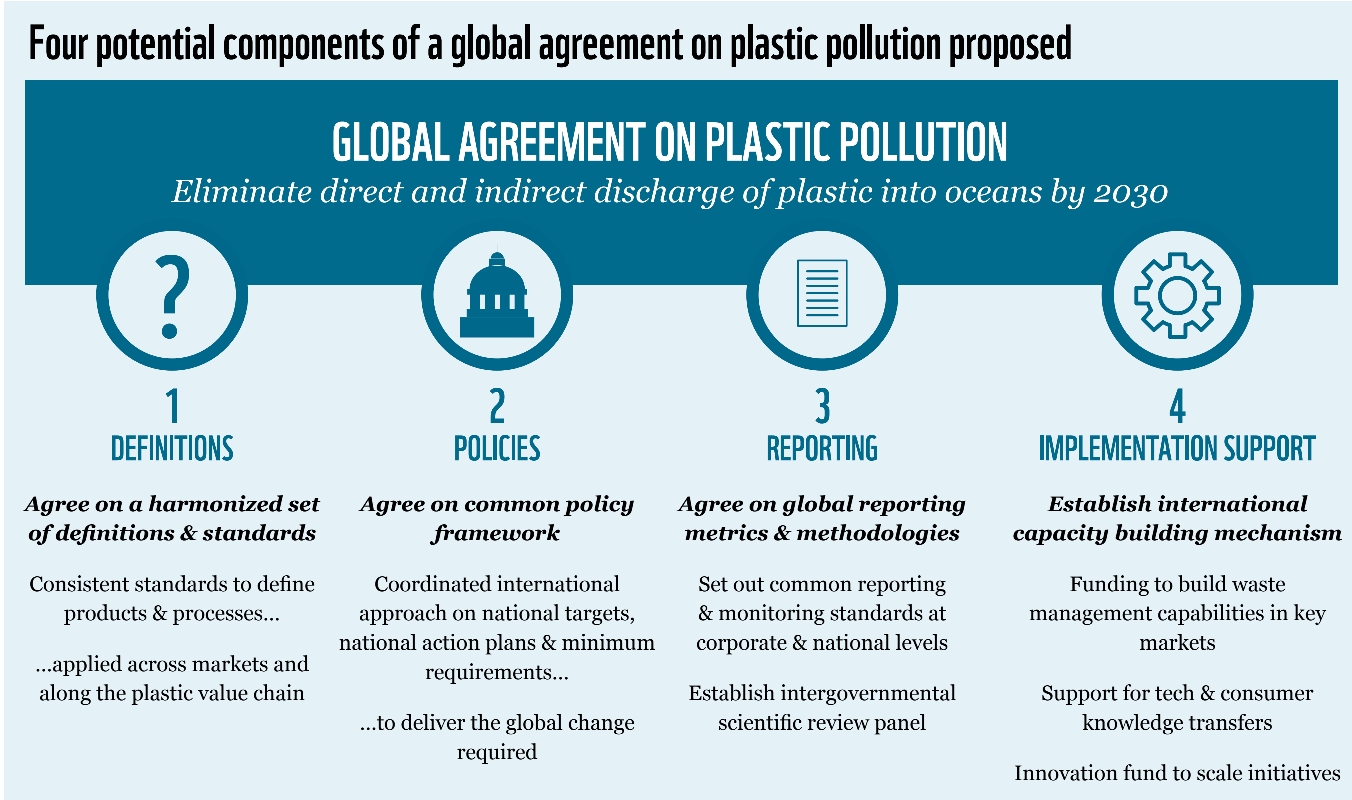
CHAPTER 4: THE WAY FORWARD

A GLOBAL TREATY COULD PROVIDE THE NECESSARY MECHANISM FOR GOVERNMENTS TO EFFECTIVELY TACKLE THE PLASTIC CRISIS AND SECURE PUBLIC SUPPORT.

A GLOBAL TREATY ON MARINE PLASTIC POLLUTION CAN BE A UNIQUE OPPORTUNITY TO TACKLE THE PLASTIC CRISIS IF IT IS AMBITIOUS ENOUGH AND ADOPTED BY MOST COUNTRIES.

An ambitious, legally binding global treaty on marine plastic pollution is likely the best tool to trigger effective global coordination and accelerate national measures and plans. Analysis by the United Nations Environment Programme (UNEP) of the effectiveness of existing and potential response options and activities on marine litter and microplastics concluded that "a well-designed international framework can address most pressures and barriers identified across all phases of the lifecycle and operate at the global scale".[183] A global treaty will provide this framework, promoting globally coordinated action on plastic, overcoming barriers to effective action, and supporting the transition to a circular economy approach *(see Figure 7)*.

Figure 7: Four potential components of a global agreement on plastic pollution proposed.[184]



Definitions and standards should be globally agreed and harmonised, such as a globally agreed definition of the word "recycling" and standards on what must be disclosed on plastic labels.

This would increase effectiveness of government efforts to tackle the plastic crisis. Harmonised definitions and standards will reduce the risk of illegal plastic imports undermining government policies (for example, what constitutes a single-use plastic bag will be consistent across countries so there is no risk of plastic bags being imported illegally). It would also facilitate recycling, for instance through labelling that discloses plastic's ingredients and providing the information required to determine whether that plastic is recyclable under the constraints of the domestic recycling system. This would reduce the risk that plastic that is recyclable is unnecessarily disposed of due to uncertainty around the ingredients.

It would also facilitate business efforts to support a circular economy for plastics. Harmonised definitions and standards would ease business operations and incentivise business innovation because there would be only one set of consistent rules to follow when trading in multiple countries. Moreover, businesses would only need to innovate once to meet the rules of all countries, rather than pursuing multiple innovations to meet various standards. Consistent standards will also reduce costs for businesses that currently struggle to comply with different fragmented standards and regulations across countries, increasing likelihood of compliance.

Policy measures across all stages of the plastic lifecycle should be considered and should be prioritised based on considerations of leakage risk, proportionality, and cost-efficiency. The new treaty should set a high common standard of action, with specific and universally applicable rules. This will ensure that the international community acts in a coordinated manner, tackling all of the costs and negative impacts. Where relevant, policy measures should be adapted to national contexts, and the treaty should provide positive incentives for technical innovation and investment in new and sustainable solutions. As an example, the new treaty could require states to introduce and implement EPR schemes for the most problematic categories of plastic. This will provide incentives for companies to pursue innovative delivery models or explore environmentally sound alternatives to plastic.

The treaty should set up a dedicated scientific body to assess and track the plastics problem. To ensure that the regime is gradually strengthened over time, countries should also be required to submit annual progress and monitoring reports. A key task for the scientific body would be to develop a globally agreed methodology for measuring key indicators and gathering data. This would provide the baselines needed to monitor progress and inform decision making. More comprehensive stocktaking at 4-5 year could also be considered, which would aim to ensure states stay on track to meet objectives and allow necessary adjustments to be made. This would also enable better understanding of the effectiveness of different measures which can inform future interventions.

Implementation support should be provided, both in the form of a financial mechanism as well as technical support, including best practice sharing among states. This will provide the support for countries to overcome some of the barriers that are currently preventing effective action. For example, the treaty will provide the necessary financing for governments with less sophisticated waste management systems to pursue the required investments in infrastructure.

The Country Deep Dives in Annex 1 provide specific examples of how the components of the treaty can support South Africa, Japan and Australia to better tackle the plastic crisis and therefore reduce the costs that the plastic lifecycle currently imposes on these countries.

THE ESTABLISHMENT OF A TREATY WILL REDUCE THE ECONOMIC, ENVIRONMENTAL AND SOCIAL COSTS AS WELL AS NEGATIVE IMPACTS OF THE PLASTIC LIFECYCLE. IT WILL ALSO BE MET WITH PUBLIC SUPPORT.

By enabling more effective government interventions, the treaty could help countries reduce the costs that are currently not included in the price of plastic. More effective government policy can support states with their transition to a circular economy, reducing the negative impacts of the plastic lifecycle. This would also bring the market cost more in-line with the lifetime cost of plastic. The global coordination will ensure all states are taking action, limiting the risk that countries may face negative impacts of plastic pollution that originated in neighbouring countries. Therefore, the treaty can help reduce the negative impacts of the plastic lifecycle and allow for countries to avoid the associated costs.

Government commitment to the treaty is likely to be met with a strong positive reaction from the public because support for action on plastic among populations is high. Public awareness of plastic pollution has grown substantially.[185] In addition, awareness and concern about other aspects of the plastic crisis is also rising. Therefore, the public now considers plastic pollution to be a significant environmental and public health issue.[186] As this awareness has grown, so has public support for government action to address the plastic crisis. For example, a UNEP survey of Asian consumers and businesses found that 91% of consumers are concerned about plastic waste, and both consumers and businesses expect greater action from governments.[187] Support specifically for a global treaty on marine plastic pollution is also growing, more than 2.1 million people from around the world have signed a WWF petition calling for a global treaty on marine plastic pollution.[188] Governments are beginning to respond. As of August 2021, a majority of the UN member states (104 countries) have explicitly called for a new global agreement.[189]

A legally binding global treaty on plastic pollution could provide the required framework to support more effective national action to combat the plastic crisis. It can also facilitate the necessary global coordination to deal with the transboundary nature of the plastic crisis. This will ensure implementation of effective policies and support the transition to a circular economy for plastics. As such, the global plastic treaty has the potential to be an effective tool in the global efforts to tackle the negative impacts associated with the plastic crisis and help reduce the significant costs currently imposed on society.

Jakarta, Indonesia, March, 2019 © WWF / Vincent Kneefel

COUNTRY DEEP DIVE 1: IMPLEMENTATION OF A GLOBAL TREATY COULD HELP SOUTH AFRICA MORE EFFICIENTLY TACKLE THE PLASTIC CRISIS AND THEREFORE AVOID THE COSTS ASSOCIATED WITH THE PLASTIC LIFECYCLE, SUCH AS THE DETRIMENTAL IMPACT OF PLASTIC ON KEY ECONOMIC INDUSTRIES AND THE THREAT POSED TO HUMAN HEALTH.

The minimum lifetime cost of the plastic produced in 2019 imposed on South Africa is approximately US$60.72 billion (+/-US$17.11 billion),[190] including damage to livelihoods and key economic industries, imposition of clean-up costs on governments and threats to the population's health.

South Africa's waste management system is struggling to deal with the national plastic waste generation, resulting in a significant amount of plastic leaking into the environment. South Africa generates an annual 41 kg of plastic waste per capita which is significantly higher than the global average of 29 kg per annum.[191] South Africa also has a weak and strained waste management system that is supported by a growing but marginalised informal waste sector. In 2018, 35% of households did not receive weekly waste collection and 29% of household waste was not collected.[192] As a result, plastic leakage is high, with an estimated 79,000 tonnes of plastic leaking into the environment per year.[193] As such, South Africa is the 11th worst global offender of leaking land-based plastic into the ocean in absolute terms.[194] There is also evidence of an increase in marine plastic debris from land-based sources within South Africa, suggesting this problem is likely to grow.[195]

This plastic leakage threatens livelihoods and key economic industries and is costing the government millions in clean-up activities. Tourism is a key industry for South Africa valued at R125 million and contributing 2.9% to South Africa's GDP.[196] Tourists are attracted to South Africa for its over 3,000 km of coastline, which is threatened by plastic pollution. For example, research demonstrates that litter density of over 10 large items per meter of beach would deter 40% of foreign tourists and 60% of local tourists from returning to Cape Town.[197] Therefore, plastic pollution is likely to negatively impact the population that rely on tourism for their livelihood. Plastic pollution also threatens South Africa's fisheries sector which many people rely on as a source of livelihood. The commercial fisheries sector directly employs 27,000 people[198] and 29,233 people are considered true subsistence fishers.[199] Studies have shown that ingestion of microplastics by fish has the potential to decrease the fish stocks and quality of catch.[200] To reduce these risks, local authorities spend a significant portion of their budgets cleaning plastic pollution and illegal dumping. Depending on the size and budget of the municipality, the cost of cleaning ranges between 1% and 26% of municipal operating expenditure for waste management.[201]

There is also strong evidence of risks posed by this plastic pollution to human health. South Africa relies on landfills as a waste management solution which exposes the human population to health risks. Many of the landfills do not meet compliance standards with an estimated 40% of plastic waste – 457,000 tonnes – ending up in non-compliant landfills in 2017.[202] This, along with high rates of uncollected waste, has made open burning a common practice. Open burning of plastic waste has been identified as a source of potentially significant risks to human health; the chemical pollutants that are released as a result have been linked to countless health issues including the development of respiratory health conditions.[203]

What has been done so far:

Since 2003, the South African government has implemented specific measures to tackle the plastic crisis. In 2003, South Africa enacted a plastic-bag legislation which included imposing a plastic bag levy and banning the use of thin-film plastic under 30 microns. This regulation was amended in 2021 and stipulated that all plastic bags (including those imported) must contain at least 50% recycled material beginning in 2023. This will gradually increase to plastic bags being manufactured from 75% recycled material from January 2025 to being entirely made from "post-consumer recyclates" in January 2027.[204] Also in 2021, the government enacted a mandatory EPR scheme on all packaging including plastic packaging which requires that obligated companies (definition in the regulations state that these are the packaging manufacturers, brand owners, importers, licensee agents and retailers) are financially and/or operationally responsible for the end-of-life activities of the packaging they place on the market.[205]

In 2020, stakeholders across the plastic packaging value chain, including the government, collectively launched the SA Plastics Pact, a national Plastics Pact which is part of the international Plastics Pact network under the Ellen MacArthur Foundation. This voluntary agreement with time bound targets is an independent pre-competitive platform made up of industry members from resin producers to the informal waste sector and is supported by various NGOs, including WWF South Africa and the IUCN.

Kwa Zulu, South Africa © shutterstock / DigArt

How a treaty can help:

While these measures are heading in the right direction, a global treaty could provide the global coordination, access to research, and financial support required to increase effectiveness of South Africa's plastic action. The treaty could provide the financial support needed for South Africa to undertake required expansions in their waste management system to improve plastic collection rates and reduce leakage. Agreed standards and methodologies for reporting and monitoring will also provide incentives for stakeholders in collection and recycling to maintain established collection and recycling rates and allow them to be held accountable. Through reporting mechanisms, the treaty can help establish a baseline of the current plastic landscape in South Africa to assess where interventions are needed and measure progress to that end. With global coordination, the treaty will increase the effectiveness of regulations such as banning single-use plastic by limiting the opportunity for illegal imports of non-compliant plastic. Therefore, a global treaty could increase the effectiveness of South Africa's efforts to tackle the plastic crisis, which could reduce the damage to South Africa's economy and risks to human health.

South Africa would also be joining many African countries in supporting the treaty, with government commitment likely to be met with strong public support. Fifty four member states endorsed a declaration calling for global action on plastic pollution at the African Ministerial Conference on the Environment (AMCEN) in November 2019.[206] A suggestion was also made for a new global agreement to combat plastic pollution to be explored further.[207] Within South Africa, there is support among the public for action on plastics with more than 2,000 members of the public emphasising their concern through a petition.[208] Two major South African retailers – Woolworths Holdings Ltd. and Pick 'n Pay - have also expressed their support for a global treaty.[209]

COUNTRY DEEP DIVE 2: IMPLEMENTATION OF A GLOBAL TREATY COULD SUPPORT AUSTRALIA'S CIRCULAR ECONOMY TRANSITION AND REDUCE COSTS ASSOCIATED WITH THE PLASTIC LIFECYCLE, INCLUDING THE DAMAGE INFLICTED ON AUSTRALIA'S ECONOMY AND WILDLIFE.

Australia is undertaking reform to transition to a more circular economy, with strategies set out in its circular economy roadmap and national plastics plan.[210, 211] However, for this plan to be realised, global opportunities and barriers need to be addressed. A legally binding treaty would provide an effective enabling framework that Australia is well placed to benefit from and contribute to.

The minimum lifetime cost of the plastic produced in 2019 imposed on Australia is approximately US$12.25 billion (+/- US$3.45 billion),[212] including damage caused to the economy and threats to Australia's wildlife.

Australia has a self-confessed plastic problem;[213] Australians consume 3.5 million tonnes of plastic waste a year,[214] including around one million tonnes of single-use plastics.[215] Australians consume more single-use plastic per capita than any other country except Singapore at 59 kg per person per year, compared with a global average of 15 kg.[216] Nearly two thirds of plastics consumed are imported,[217] and 93% of plastic packaging on the market is virgin plastic.[218] While plastic consumption continues to rise, improved recovery rates (11.5% in 2018-2019) are not keeping pace. An estimated 130,000 tonnes of plastic waste leaks into the environment every year.[219]

Plastic pollution is damaging the Australian economy by negatively impacting key economic industries including fisheries, shipping and tourism. Australia's marine economy as a fraction of GDP is the ninth highest out of the 21 APEC countries.[220] The total cost of damage to Australia's marine economies in 2015 was estimated at more than US$430 million; US$41 million in damages to fisheries and aquaculture, US$59 million to shipping, and US$330 million to marine tourism.[221] These are direct costs only and exclude a wide range of remedial (clean-up) and indirect costs.

Plastic poses significant threats to Australia's wildlife. An estimated 15,000-20,000 turtles have been affected by entanglement in abandoned, lost or derelict fishing gear in the northern Gulf region (off the northern coast of Australia).[222] Ingesting just one piece of plastic increases a turtle's chance of dying by 22%, and 52% of all marine turtles are estimated to have ingested debris.[223] Short-tailed shearwaters, Australia's most numerous seabird, are also impacted by plastics with more than 67% of them found to have ingested plastic.[224] Australian scientists are at the forefront of documenting this issue, and consistently advocating for policy solutions that prevent plastic leakage into the environment.[225]

What has been done so far:

Australia is taking decisive action to tackle the plastic crisis. Environment ministers at national and sub-national levels have agreed on eight of the most problematic and unnecessary single-use plastics to be phased out by 2025.[226] State and territory governments have already started phasing out these products. The Australian government has banned the export of unprocessed plastic waste from July 2021[227] and established clear recycling targets to be achieved by 2025. These include 100% of packaging being reusable, recyclable or compostable, 70% of plastic packaging going on to be recycled or composted, and for all plastic packaging to comprise 20% recycled content.[228] An investment of US$100 million in the Australian Recycling Investment Fund to build domestic recycling infrastructure[229] is complemented by targeted investment to tackle ghost gear (US$14.8 million[230]) and regional investment to strengthen action against plastic pollution across the Pacific (US$16 million[231]).

How a treaty can help:

A global treaty could enhance Australia's efforts to transition to a circular economy for plastics. A global approach to addressing plastic pollution that addresses the full lifecycle of plastics could positively impact on five of the ten key challenges to circularity identified in Australia's circular economy roadmap.[232] These include recyclability of imported plastics, demand for recycled products, standards for recycled materials and products, and lifecycle research on plastics. While Australia's circular economy roadmap provides a framework for domestic transformation, international factors – including the global trade in plastic, research, and innovation – have the capacity to support or undermine Australia's transition efforts. An effective global agreement would provide a supportive and complementary framework for domestic action.

Conversely, a lack of global coordination could undermine Australia's efforts. Australian coastlines are impacted by both domestic and international marine plastic pollution. While the majority of ocean pollution comes from domestic sources, research indicates that international sources do contribute to the problem in Northern Australia and other locations.[233] Of the top 20 plastic emitters into the ocean globally, half are in the Asia-Pacific region.[234] Even if domestic policies effectively reduce Australia's plastic leakage into the ocean, Australia will continue to be impacted by marine plastic pollution if neighbouring countries fail to reduce their plastic leakage. A treaty could mitigate this risk through a concerted global effort to reduce pollution at the source, with a strong focus on the largest emitters.

The treaty could also provide the opportunity for Australia to become a recognised global leader on plastic pollution by sharing best practice developed by governments, scientists, NGOs, businesses and communities. Australia's unique approach to the plastic crisis draws on its geography, strong public support, innovation and a strong connection to its pristine natural environments and wildlife. Governments are increasingly collaborating to transition to a circular economy and build domestic recycling capacity. Australian scientists make a substantial contribution to the global evidence base on plastic pollution impacts and solutions. And Australian innovation, epitomised by movements such as Plastic Free July and products such as KeepCup, is demonstrating sustained impact internationally. Australia has a significant contribution to make to a global approach, that could be readily shared with other countries via the technical support component of the treaty.

Great Barrier Reef, Australia, 2006
© Troy Mayne / WWF

COUNTRY DEEP DIVE 3: IMPLEMENTATION OF A GLOBAL TREATY COULD HELP JAPAN AVOID COSTS ASSOCIATED WITH THE PLASTIC CRISIS INCLUDING THE DETRIMENTAL IMPACT OF PLASTICS ON THE FISHING SECTOR AND GHG EMISSIONS, WHILE PROVIDING JAPAN THE OPPORTUNITY TO CEMENT ITSELF AS A GLOBAL LEADER IN PLASTIC ACTION.

The minimum lifetime cost of the plastic produced in 2019 imposed on Japan is approximately US$108.69 billion (+/-US$30.64 billion), [235] including threats to the fisheries and aquaculture industry.

Japan is the second highest per capita plastic packaging waste generator in the world, with plastic being an important part of Japanese commerce. Plastic is an integral part of society in Japan, with single-use plastic wrapped around individual pieces of food such as bananas for food safety reasons. As such, Japan produces around nine million tonnes of plastic waste per year,[236] making it the second highest per capita plastic packaging waste generator in the world, second only to the US.[237]

Plastic leakage from Japan and its neighbours is polluting the water bodies surrounding Japan and threatening both tourism and the fisheries and aquaculture industry. Plastic pollution is overwhelming the bodies of water surrounding Japan; plastic levels in East Asian seas are 16 times greater than in the North Pacific and 27 times greater than in the world oceans.[238] The Kansai Regional Union estimates that 3 million plastic bags and 6.1 million pieces of vinyl linger in Osaka Bay. Lots of debris is found in the offshore areas surrounding Japan, much of which was traced back to Japanese sources.[239] This waste is impacting the tourism industry with plastic waste washing up on many of Japan's beaches and deterring visitors. This has the potential to be highly damaging to Japan's economy, with the travel and tourism industry contributing more than USD$300 billion in 2019.[240] This pollution also affects Japan's fisheries; nearly 80% of the 64 Japanese anchovies caught during a survey of Tokyo Bay had plastic waste inside their digestive systems.[241] This can impact both the volume and quality of the fishing yield, leading to reduced revenues for the fishery sector and putting significant numbers of jobs at risk. In 2018, employment in the seafood sector, including processing, accounted for 202,430 jobs.[242] It can also increase the risk of ingestion of microplastics by humans through consumption of the contaminated fish.

What has been done so far:

Japan has developed a sophisticated waste management system which aims to recycle or recover significant proportions of plastic waste, therefore limiting leakage into the environment. In 2000, the Basic Act for Establishing a Sound-Material-Cycle Society came into force.[243] The act aimed to promote the three Rs (reduce, reuse, recycle) and ensure proper waste management. As part of this, waste is mandatorily separated and plastic recycled, with consumers educated on how to sort and dispose of waste. There is relatively high compliance, with the Japanese population committed to undertaking the sometimes complex task of sorting their waste. This is a relatively efficient system with strong potential to reduce plastic leakage; according to the UN, an effective waste management system means that Japan accounts for relatively limited leakages of single-use plastics in the environment.[244]

However, there is still a significant opportunity for the government to improve the effectiveness of their plastic action and reduce the negative consequences of plastic production, use, and leakage in Japan. According to official numbers, in 2018 Japan recycled or recovered 84% of the plastic collected.[245] However, this includes the 56% of plastic waste that is incinerated for energy.[246] Therefore, the majority of plastics are not being recycled into new products, necessitating new virgin plastic production. Additionally, although Japan has implemented emissions controls to reduce the chemical pollutants produced from incineration, incineration is still a net contributor of GHG emissions. Therefore, Japan's reliance on incineration for waste management is contributing to the climate crisis on two fronts; directly from the emissions produced from the process itself and indirectly by contributing to GHG emissions from new virgin plastic production. There is also no regulation on primary microplastics such as microbeads and microfibers which municipal sewage systems are typically unable to remove. As a result, the particles pass through the plant and are discharged into nearby waters, further contributing to plastic leakage and imposing the associated costs.

How a treaty can help:

Support for a global treaty, expressed by Japan in July 2021, confirms Japan's leading voice in action on plastics, whilst providing an opportunity to increase the effectiveness of government policies to tackle plastic. At the G20 Osaka Summit held in June 2019, Japan proposed the "Osaka Blue Ocean Vision", which aims to reduce additional pollution by marine plastic litter to zero by 2050.[247] Japan's decision to support the development of an international treaty on marine plastic pollution provides a new platform to accelerate the delivery of this ambition ahead of the targeted date. The next important step for the Japanese government is to co-sponsor the draft resolution which would allow to start the negotiation of a new treaty at the 5th session of the UN Environment Assembly. Japan's support will be crucial to achieving a successful outcome at the meeting in February 2022. The treaty has potential to also increase the effectiveness of Japan's current plastic action. Pursuing the establishment of an EPR scheme will help shift some of the burden from municipalities to companies, providing the financial incentive to switch to other materials or pursue innovative delivery models. This can help to reduce Japan's plastic consumption and therefore waste production. Coordination can reduce leakage from neighbouring countries, diminishing the risk of it travelling through water streams into Japanese waters and causing detrimental impacts. Therefore, the treaty will help increase the effectiveness of government action to tackle the plastic crisis, reducing the negative impacts on the tourism and fisheries and aquaculture industries.

Importantly, public support for a global treaty is high among the Japanese population; 61% of Japanese citizens believe that Japan should be taking a leadership role in promoting a new international treaty to tackle the escalating problem of plastic pollution.[248]

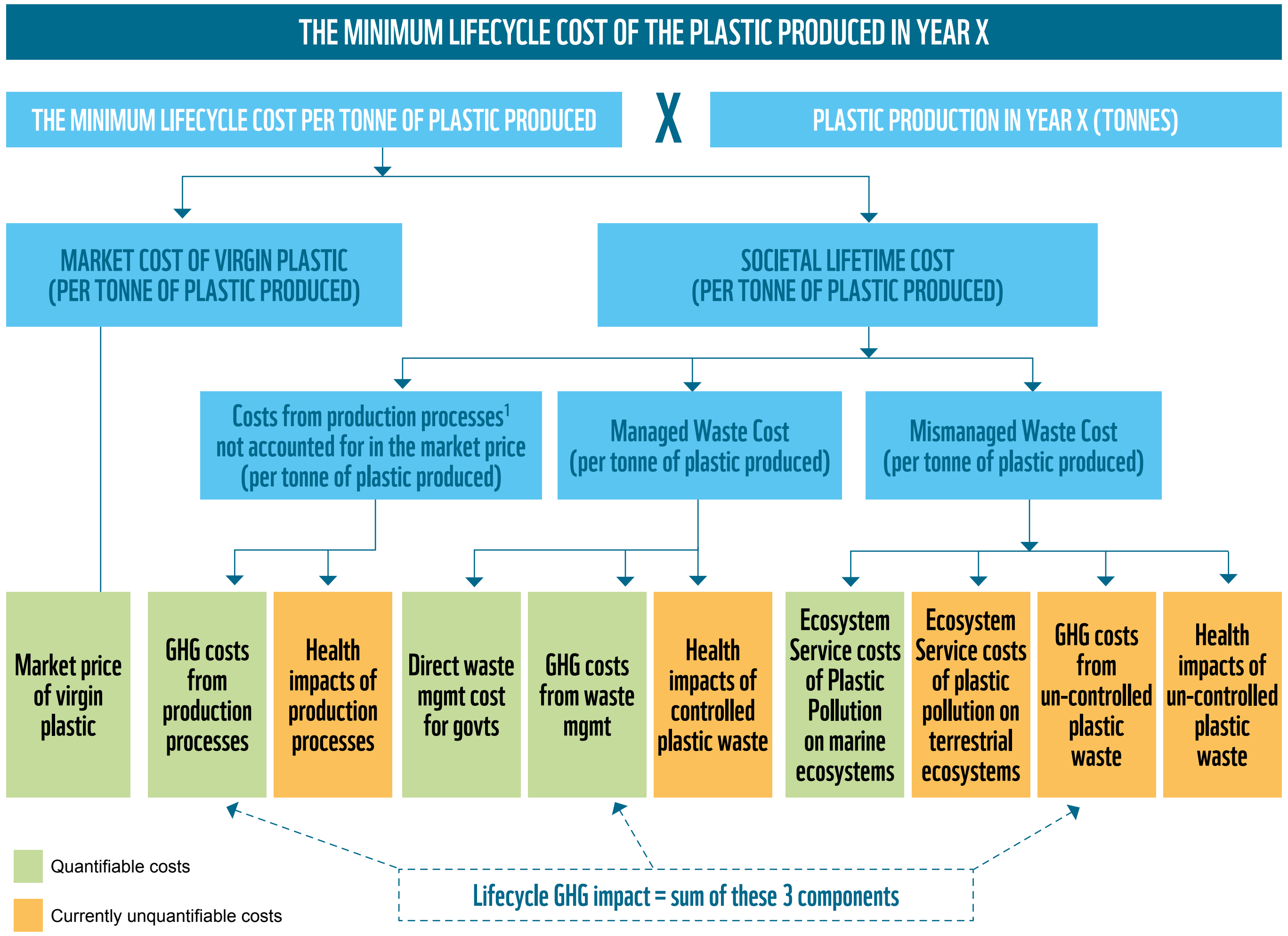
Hokkaido, Japan, 2020 © alamy

ANNEX 2: METHODOLOGY

This annex describes the methodology used by the authors to estimate the minimum lifetime cost of plastic. As noted in the report, this model only includes those components of the plastic lifetime that are currently quantifiable. Quantifiable components refer to impacts of the plastic lifecycle for which peer-reviewed publications are available and there is sufficient data to allow a best-guess estimate. An overview of other potential costs, not included in this model, has been provided in the report.

Lifetime cost of plastic figures: The objective of this model is to provide a more comprehensive view of the cost of plastic, building upon existing publications by the Pew Charitable Trusts, WEF, Deloitte, Carbon Tracker and various academic papers.[249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261]. This poses two challenges: i) for some components of the total cost of plastic, data does not exist yet, and ii) for other components, data exists but sometimes still needs to be made more precise or validated with additional research. This model incorporates several cost dimensions that have been documented enough to allow a cost estimate (called "quantifiable costs" in the below diagram). Dimensions for which there is insufficient data to provide a cost estimate (called "currently unquantified costs" in the below diagram) have been omitted from the model. The sources used for the quantifiable cost dimensions are either the best available data on different impacts of the plastic crisis or provide monetary estimations based on data that is available, often with the caveat that they are "best-guess" estimates. Given that there are many impacts of the plastic lifecycle that have not been documented enough yet, the estimate provided by this model is the minimum cost that the plastic produced in 2019 will impose over its entire lifetime, from the point the raw materials were extracted to the point at which this plastic has fully degraded. The approach is outlined in more detail below:

Figure 8: Overview of the dimensions that make up the minimum lifetime cost of plastic.



1. This includes extraction, resin production and conversion processes

MODEL CALCULATIONS:

1. Market cost of plastic

- **The following inputs were used to estimate the market cost of the plastic produced in 2019:**
  - **Input 1:** Global price of different plastic polymers for 2019 provided by Statista.[262]
  - **Input 2:** Global share of production of the different plastic types for 2018 provided by Statista.[263]
  - **Input 3:** Plastic production in 2019 estimated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH as **368 million metric tonnes.**[264]
- **The following steps were taken to estimate the market cost of the plastic produced in 2019:**

  Step 1: To calculate the price per tonne of other plastic polymers for 2019, the authors used the average of the other polymer prices as a proxy. This estimated the price of the other category in 2019 as **~US$1,020.98.**

  Step 2: The authors then used the production share estimated for each plastic polymer in 2018 as a proxy for the production share in 2019 to calculate a weighted average cost per tonne of plastic in 2019 (for example, PET cost in USD*PET production share + HDPE cost in USD*HDPE production share etc.). This estimated the average cost of plastic per tonne as **~US$1,006.67.**

  Step 3: To calculate the market cost of the plastic produced in 2019, the authors multiplied the estimated cost per tonne (US$1,006.67) by the tonnes of plastic produced in 2019 (368 million). **This estimated the market cost of the plastic produced in 2019 as ~US$370 billion.**

2. Waste management costs:

- **The following inputs were used to estimate the waste management cost of the plastic produced in 2019:**
  - **Input 1:** Data on municipal solid plastic waste management stages provided by the Pew Charitable Trusts, collected for their *Breaking the Plastic Wave* report.[265] The Pew Charitable Trusts provided mass and cost data for each of the stages of the waste management process globally for 2016 for municipal solid plastic waste. This included:

    • **Formal collection:** waste collected by the formal sector.[266]

    • **Formal sorting:** waste sorted by the formal sector, this includes waste that was imported[267] and domestic waste that was formally collected for recycling.[268]

    • **Informal collection and sorting:** waste collected and sorted by the informal sector.[269] This includes waste that was initially informally collected, and waste recovered from dumpsites or unsanitary landfill by informal waste collectors.[270, 271]

    • **Disposal mass and cost:** waste that was disposed of by either engineered landfill or incineration with energy recovery.[272, 273]

    • **Recycling mass and cost:** waste that was recycled either by open-loop or closed-loop mechanical recycling processes. Waste that was mechanically recycled may have come from formally sorted or informally collected and sorted waste.[274, 275] The sale prices for different recyclates was based on a composition of high-value plastics (PET, HDPE, and PP).
  - Mass and cost data for these dimensions was provided for eight different geographic archetypes. The archetypes are divided into four groups depending on country income, according to World Bank definitions: high-income (HI) economies; upper middle-income (UMI) economies; lower middle-income (LMI) economies; and low-income (LI) economies; as well as according to United Nations urban-rural classifications. All cost data was reported in 2018 US$.
  - **Input 2**: Proportion of the plastic produced in 2019 that becomes waste estimated as **70%**. This is based on a study by Geyer *et al.*[276] that estimated 70% of the cumulative plastic produced between 1950-2015 has become waste. The authors of this report also assumed that this proportion has remained constant over time.
  - **Input 3:** Plastic production in 2019 estimated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH as **368 million metric tonnes.**[277]
- **The following steps were taken to estimate the waste management cost of the plastic produced in 2019:**

  Step 1: To calculate the municipal plastic waste management cost in 2016, the authors calculated the cost of the different waste management stages using the data provided by the Pew Charitable Trusts and summed the cost of all the stages together. This estimated the total waste management cost in 2016 as **~US$26.6 billion.**

  Step 2: The authors converted the estimated total waste management in 2016 in 2018 US$ to 2019 US$ using data on the U.S consumer price index from The U.S. Labor Department's Bureau of Labor Statistics. This estimated the total municipal solid plastic waste management in 2016 in 2019 US$ as **~US$27.0 billion.**

  Step 3: To calculate the cost per tonne of municipal solid plastic waste in 2016, the authors divided the total waste management cost in 2016 ($27 billion) by the municipal solid plastic waste generated in 2016 (215 million tonnes). This estimated the cost per tonne of plastic waste as **~US$125.68.**

  Step 4: To estimate the total tonnes of plastic produced in 2019 that will become waste, the authors multiplied the tonnes of plastic produced in 2019 (368 million) by the proportion of plastic produced that becomes waste (~70%). This estimated that **~257.6 million tonnes** of the plastic produced in 2019 will become waste.

  Step 5: To estimate the cost of waste management attributable to the plastic produced in 2019, the authors multiplied the waste management cost per tonne (US$125.68) by the tonnes of plastic produced in 2019 that becomes waste (257.6 million). This uses the cost per tonne of municipal solid plastic waste as a proxy for a cost per tonne of plastic waste overall and uses the cost per tonne of waste in 2016 as a proxy for the cost per tonne of waste in 2019. **This estimated the cost of waste management for the plastic produced in 2019 as ~US$32 billion.**[278]

3. Ecosystem service cost of plastic pollution on marine ecosystems:

- **The following inputs were used to estimate the ecosystem service cost of the plastic produced in 2019:**
  - **Input 1:** Value of ecosystem services provided by the ocean in 2011 estimated by Constanza et al. as **~US$49.7 trillion** in 2007 dollars.[279] While there are other papers on the importance of marine ecosystem services, Costanza et al. provide a value for global ecosystem services which is based on a figure from Costanza *et al.* 1997[280] using updated ecosystem service values and land use change estimates and updated data. They also respond to criticisms of the 1997 paper to increase the robustness of their valuation.
  - **Input 2:** Reduction in ecosystem services because of marine plastic pollution estimated by Beaumont *et al.* as between **1-5%.**[281] This was based on an expert scientific panel reviewing available evidence on the damage imposed by plastic on each ecosystem service. This includes damage posed by plastic on all regulating, cultural and regulatory services provided by the ocean. Only where sufficient evidence was available were reductions estimated.
  - **Input 3:** Stock of plastic in the ocean in 2011 estimated by Beaumont *et al.*[282] as **between 75 million[283]-150 million tonnes.[284]**
  - **Input 4:** Time horizon of plastic pollution in the ocean assumed to be **infinity.** This is based on the fact that most plastics will remain permanently in the ocean continuing to break down into smaller and smaller particles and plastic continues to cause harm regardless of how small a piece it becomes. More research is emerging that outlines the harmful impacts of micro and nanoplastic. However, in the methodology, due to the use of a discount rate *(see input 5)*, 85% of the lifetime cost comes from the costs incurred in the first 100 years, and 95% from the costs incurred in the first 150 years; The costs incurred after the first 200 years are being discounted by more than 98% and do not significantly contribute to the lifetime cost estimates.
  - **Input 5:** Social discount rate (SDR) estimated as 2% based on Drupp *et al.* where more than 2/3 of 200 experts were comfortable with a median SDR of **2%.** [285]
  - **Input 6:** Plastic production in 2019 estimated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH as **368 million metric tonnes.**[286]
  - **Input 7:** Proportion of the plastic produced in 2019 that becomes waste estimated as **70%.** This is based on a study by Geyer *et al.*[287] that estimated 70% of the cumulative plastic produced between 1950-2015 has become waste. The authors of this report also assumed that this proportion has remained constant over time.
  - **Input 8:** Tonnes of municipal solid plastic waste and primary microplastics[288] that leaked into the ocean in 2016 estimated as **11.1 million tonnes** in *Breaking the Plastic Wave.*[289]
  - **Input 9:** Tonnes of fishing gear that leak into the ocean annually estimated as **0.6Mt** by Boucher and Friot.[290]
  - **Input 10:** Proportion of at-sea based sources of leakage into the ocean accounted for by fishing gear estimated **as 65%** as per Arcadis 2012,[291] the other 35% coming from shipping which could be domestic waste from the ship, leaked cargo, or ropes.
  - **Input 11:** Plastic waste generated in 2015 estimated by Geyer *et al.*[292] as **302 million tonnes.**
- **The following steps were taken to estimate the ecosystem service cost of the plastic produced in 2019:**

Step 1: The authors converted the value of marine ecosystem services in 2011 in 2007 US$ into 2019 US$ using data on the U.S consumer price index from The U.S. Labor Department's Bureau of Labor Statistics. This estimated the value of ecosystem services in 2011 in 2019 US$ as **~US$61.3 trillion.**

Step 2: To estimate the minimum cost imposed by plastic pollution in the ocean in 2011, the authors took 1% of $61.3 trillion (i.e., the most conservative end of the 1-5% range from the Beaumont *et al.* paper[293]). This estimated the minimum cost imposed by plastic pollution in the ocean as **~US$613 billion.**

Step 3: To estimate the cost per tonne of plastic pollution, the authors divided the cost imposed by plastic pollution in the ocean ($613 billion) by the lower bound and upper bound stock of plastic in the ocean (75 million and 150 million). This estimated the minimum cost per tonne as between **~US$4,085-8,171.** This estimate is an average cost per tonne of plastic. However, in reality the cost per tonne will change depending on the type and size of the plastic, where the plastic was emitted from and where it moves to. Therefore, each tonne of plastic in the ocean is likely to have a cost that is either greater or smaller than the average based on these factors.

Step 4: Several of the main contributors to plastic waste that end up in the ocean can take more than 400 years to degrade, with research showing that plastic can remain in the ocean for thousands of years. Therefore, plastic waste will generate costs for societies and governments for at least several hundreds and even potentially thousands of years. However, given the uncertainty of estimating costs in the future, the authors built this model conservatively. They used a perpetual net present value formula to estimate the lifetime cost per tonne of plastic in the ocean. A net present value formula calculates the present value of a future stream of costs which discounts the future costs using a discount rate (the authors used the social discount rate of 2%), this gives less weight to costs that will occur in the long term future. This estimated the lifetime cost per tonne imposed by plastic in the ocean as **~US$204,270-408,541,** with 85% of this cost made up of costs that societies and governments will face in the next 100 years (or 95% in the next 150 years).

Step 5: To calculate the proportion of plastic waste that becomes waste, the authors summed the tonnes of plastic leakage from municipal solid waste and primary microplastics from *Breaking the Plastic Wave*[294] (9.8 million from MSW and 1.3 million from primary microplastics) with the annual tonnes of at-sea sources of leakage (~923,076[295]). This estimated annual leakage into the ocean in 2016 as ~12 million tonnes. They then divided this by total plastic waste generation in 2015 (302 million tonnes) which estimated the proportion of plastic waste entering the ocean as **~4%.** This estimate includes the simplifying assumption that plastic waste generation in 2015 can act as a proxy for plastic waste generation in 2016. This estimate is an underestimate because it does not include leakage from non-municipal solid plastic waste or secondary microplastics. However, studies have shown that plastics from electronics, building and construction, and transport are not often observed as ocean debris[296]. As such the authors are comfortable using their estimate as a conservative estimate of the proportion of plastic waste that enters the ocean.

Step 6: To calculate the total tonnes of the plastic produced in 2019 that will enter the ocean, the authors multiplied the tonnes of plastic produced in 2019 (368 million) by the proportion of plastic produced that becomes waste (70%), then multiplied that result by the proportion of plastic waste that leaks into the ocean (~4%). This estimated the tonnes of plastic leaking into the ocean attributable to the plastic produced in 2019 as **~10 million.**

Step 7: To estimate the ecosystem service cost induced by the plastic produced in 2019, the authors multiplied the plastic produced in 2019 that will enter the ocean (10 million tonnes) by the lifetime impact on ecosystem services per tonne of plastic entering the ocean (US$204,270-408,541). This estimated the ecosystem service cost imposed over the lifetime of the plastic produced in 2019 as **~US$2.1-4.2 trillion.** While research indicated 2% as the most relevant discount rate value (as explained above), the authors also ran scenario analyses to confirm how the figure would change under a higher discount rate, which would place an even lower weight on long term future costs. As the authors used the perpetuity net present value formula, doubling the discount rate to 4% would mechanically half the ecosystem service cost imposed over the lifetime of the plastic produced in 2019, to between ~US$1.0-2.1 trillion. However, an important nuance should be observed: while this total is halved, the costs occurring future are significantly less impacted. If current decision-makers focus on the costs that will occur within the next decades, the difference in the estimates from an increased discount rate is less significant. Taking the period between now and 2050, which is frequently used timeline for climate action, using a 2% discount rate leads to cumulative discounted costs of ~US$938 billion by 2050 and using a 4% discount rate still leads to cumulative discounted costs of US$724 billion by 2050, only 23% lower.

Step 8: The authors then estimated the median ecosystem service cost imposed over the lifetime of the plastic produced in 2019 as **~US$3.1 trillion.**

4. Cost of lifecycle GHG emissions:

- **The following inputs were used to estimate the cost of lifecycle GHG emissions from the plastic produced in 2019:**
  - **Input 1:** Total GHG emissions from across the plastic lifecycle in 2015 provided by Zheng & Su.[297] These figures are limited by the fact that they do not provide estimates for the use phase of the plastic lifecycle or from mismanaged plastic waste. However, data on these components is currently not comprehensive enough to provide robust estimates. Therefore, the authors were comfortable in using the Zheng & Su figures as a conservative estimate for GHG emissions from the plastic lifecycle. These figures also do not include the displacement of carbon intensive virgin polymer production by recyclates. The authors chose to use the Zheng & Su[298] estimate rather than the estimate provided by CIEL (0.8Gt)[299] because it included the conversion process and a breakdown of the emissions from each of the lifecycle stages: GHG emissions across the plastic lifecycle in 2015.

Table 2: GHG emissions across the plastic lifecycle in 2015.[300]

Lifecycle Stage	Description	Emissions
Resin Production	Includes all activities from cradle to polymer-production factory gate	1,085
Conversion	Covers the manufacturing processes that turn polymers into final plastic products	535
End-of-Life	Includes the treatment and disposal processes of plastic waste	161
Total		1,781

  - **Input 2:** Cost of carbon estimated as **US$100** in line with the average price from IPCC based on IAMs used in the IPCC SR15 report[301]. This is based on the required cost to reach a certain temperature reduction under given abatement technology.
  - **Input 3:** Plastic production in 2015 estimated by Geyer *et al.*[302] as **380 million tonnes.**
  - **Input 4:** Plastic waste generated in 2015 estimated by Geyer *et al.*[303] as **302 million tonnes.**
  - **Input 5:** Proportion of the plastic produced in 2019 that becomes waste estimated as **70%.** This is based on a study by Geyer *et al.*[304] that estimated 70% of the cumulative plastic produced between 1950-2015 has

become waste. The authors of this report also assumed that this proportion has remained constant over time.

- **Input 6:** Plastic production in 2019 estimated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH as **368 million metric tonnes.**[305]

- **The following steps were taken to estimate the cost of lifetime GHG emissions from the plastic produced in 2019:**

Step 1: The authors estimated the total emissions from production processes in 2015 by summing the emissions from resin production (1.085Gt) and conversion (535Mt). This estimated the total emissions from production processes in 2015 as **~1.6Gt.**

Step 2: The authors calculated the emissions from production processes per tonne of production by dividing total emissions from production processes (1.6Gt) by the estimated tonnes of plastic produced in 2015 (380 million). This estimated **~4.3 tonnes of CO_2e** per tonne of plastic produced.

Step 3: To estimate the emissions from production processes of the plastic produced in 2019, the authors multiplied the tonnes of plastic produced in 2019 (368 million) by the tonnes of CO_2e per tonne of plastic produced (~4.3). This estimated the emissions from production processes of the plastic produced in 2019 as **~1.6 billion tonnes of CO_2e**. This includes the simplifying assumption that the CO²e intensity of plastic production processes has stayed constant since 2015.

Step 4: To calculate the emissions from end-of-life processes per tonne of plastic waste, the authors divided the end-of-life emissions in 2015 (162 Mt) by the tonnes of plastic waste generated in 2015 (302 million). This estimated **~0.53 tonnes of CO_2e** per tonne of waste generated.

Step 5: To calculate the tonnes of plastic produced in 2019 that will become waste, the authors multiplied the tonnes of plastic produced in 2019 (368 million) by the proportion of plastic produced that becomes waste (70%). This estimated ~**258 million tonnes** of the plastic produced in 2019 will become waste.

Step 6: To calculate the total end-of-life emissions attributable to the plastic produced in 2019, the authors multiplied the end-of-life emissions per tonne of plastic waste (0.53 tonnes of CO_2e) by the tonnes of plastic produced in 2019 that becomes waste (258 million). This estimated the emissions from end-of-life processes attributable to plastic produced in 2019 as ~**137 million tonnes of CO_2e**. This includes the simplifying assumption that the CO_2e intensity of the end-of-life process has remained constant since 2015.

Step 7: To calculate the total emissions from across the lifetime of the plastic produced in 2019, the authors summed the estimated emissions from production processes of the plastic produced in 2019 (1.6Gt) with the emissions from the end-of-life stage of the plastic produced in 2019 (137 Mt). This estimated the total emissions from across the lifetime of the plastic produced in 2019 as **~1.7Gt.**

Step 8: To calculate the total cost of GHG emissions incurred over the lifetime of the plastic produced in 2019, the authors multiplied the CO_2e from the plastic lifetime (1.7 billion tonnes) by the cost of carbon per tonne (US$100). **This estimated the cost of GHG emissions from the lifetime of the plastic produced in 2019 as ~ US$171 billion.**

Quantifiable societal lifetime cost of plastic over time:

- **The following inputs were used to estimate the societal lifetime cost of plastic over time:**

- **Input 1:** Projected growth of plastic production provided by WEF. [306] They state that according to ICIS, projected industry growth is **3.8% annually** between 2015-2030 and according to International Energy Agency's World Energy Outlook 2015[307], the projected growth is **3.5% annually** from 2030-2050.
- **Input 2:** Plastic production in 2019 estimated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH as **368 million metric tonnes.**[308]
- **Input 3:** Societal lifetime cost of the plastic produced in 2019 estimated by the authors of this report as **~US$2.3-4.4 trillion.** This is the sum of: i) waste management cost, ii) ecosystem service cost, iii) cost of GHG emissions.
- **Input 4:** Social discount rate estimated as 2% based on Drupp *et al.* survey where more than 2/3 of 200 experts were comfortable with a median SDR of 2%.[309]

The following steps were taken to estimate the societal lifetime cost of plastic over time:

Step 1: To estimate the future plastic production up to and including 2040, the authors started from the plastic production in 2019 (368 million tonnes) and applied the projected growth rate of 3.8% to estimate annual plastic production up to and including 2030. The authors then applied the projected growth rate of plastic from 2030-2050 (3.5%) to estimate plastic production for 2031-2040.

Step 2: To calculate the societal lifetime cost per tonne of plastic produced, the authors divided the societal lifetime cost of the plastic produced in 2019 (US$2.3-4.4 trillion) by the estimated tonnes of plastic produced in 2019 (368 million). This estimated the societal lifetime cost of plastic per tonne of plastic produced as between **~US$6,244-11,937.**

Step 3: To calculate the societal lifetime cost of plastic from the plastic produced in each year from 2020-2040, the authors multiplied the societal lifetime cost of plastic per tonne ($6,244-11,937) by the projected plastic production in each year.

Table 3: Model outputs - Cost estimates:

Headline outputs	Lower Bound	Upper Bound	Median
Market Cost of the Plastic Produced in 2019	~US$370 billion	~US$370 billion	~US$370 billion
Waste Management Costs Attributable to the Plastic Produced in 2019	~US$32 billion	~US$32 billion	~US$32 billion
Ecosystem Service Costs of Plastic Pollution Attributable to the Plastic Produced in 2019 on Marine Ecosystem Services	~US$2.1 trillion	~US$4.3 trillion	~US$3.1 trillion
Cost of the Lifetime GHG Emissions of the Plastic Produced in 2019	~US$171 billion`	~US$171 billion	~US$171 billion
Total Quantifiable Cost of the Plastic Produced in 2019	**~US$2.7 trillion**	**~US$4.8 trillion**	**~US$3.7 trillion**
Total Quantifiable Societal Lifetime Cost (sum of Waste Management, Ecosystem Service and GHG costs)	**~US$2.3 trillion**	**~US$4.4 trillion**	**~US$3.3 trillion**

Table 4: Model output – Present value of the projected societal lifetime cost of (based on plastic production volume forecasts, and 2019 induced cost per ton):

Year	Lower Bound Cost	Upper Bound Cost	Median Cost
2019	US$2,297,876,557,030	US$4,392,761,042,731	US3,345,318,799,881
2020	US$2,385,195,866,197	US$4,559,685,962,354	US$3,472,440,914,276
2021	US$2,475,833,309,113	US$4,732,954,028,924	US$3,604,393,669,018
2022	US$2,569,914,974,859	US$4,912,806,282,023	US$3,741,360,628,441
2023	US$2,667,571,743,904	US$5,099,492,920,740	US$3,883,532,332,322
2024	US$2,768,939,470,172	US$5,293,273,651,728	US$4,031,106,560,950
2025	US$2,874,159,170,039	US$5,494,418,050,494	US$4,184,288,610,266
2026	US$2,983,377,218,500	US$5,703,205,936,412	US$4,343,291,577,456
2027	US$3,096,745,552,803	US$5,919,927,761,996	US$4,508,336,657,400
2028	US$3,214,421,883,810	US$6,144,885,016,952	US$4,679,653,450,381
2029	US$3,336,569,915,395	US$6,378,390,647,596	US$4,857,480,281,495
2030	US$3,463,359,572,180	US$6,620,769,492,205	US$5,042,064,532,192
2031	US$3,584,577,157,206	US$6,852,496,424,432	US$5,218,536,790,819
2032	US$3,710,037,357,708	US$7,092,333,799,287	US$5,401,185,578,498
2033	US$3,839,888,665,228	US$7,340,565,482,262	US$5,590,227,073,745
2034	US$3,974,284,768,511	US$7,597,485,274,141	US$5,785,885,021,326
2035	US$4,113,384,735,409	US$7,863,397,258,736	US$5,988,390,997,073
2036	US$4,257,353,201,148	US$8,138,616,162,792	US$6,197,984,681,970
2037	US$4,406,360,563,188	US$8,423,467,728,490	US$6,414,914,145,839
2038	US$4,560,583,182,900	US$8,718,289,098,987	US$6,639,436,140,943
2039	US$4,720,203,594,301	US$9,023,429,217,451	US$6,871,816,405,876
2040	**US$4,885,410,720,102**	**US$9,339,249,240,062**	**US$7,112,329,980,082**

Endnotes

1 Parker, L. (2019) "The world's plastic pollution crisis explained", National Geographic, 7 June, viewed 6 August 2021,https://www.nationalgeographic.com/environment/article/plastic-pollution.

2 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).

3 CIEL, 2019. *Plastic and Health: The Hidden Costs of a Plastic Planet*.

4 CIEL, 2019. *Plastic and Climate: The Hidden Costs of a Plastic Planet*.

5 UNEP, 2018. *Single-use plastics: A Roadmap for Sustainability*.

6 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

7 WWF, 2020. *Stop Ghost Gear: The most deadly form of marine plastic debris*.

8 Beaumont N.J. *et al.* (2019) "Global ecological, social and economic impacts of marine plastic", Marine Pollution Bulletin, 142, pp 189-195.

9 Deloitte, 2019. *Price Tag of Plastic Pollution*.

10 The authors calculate the lifetime cost of plastic by using the perpetuity formula with a discount rate of 2% as per Drupp, M.A. et al. (2018) "Discounting Disentangled", *American Economic Journal: Economic Policy*, 10(4), pp 109-34. Consequently, 85% of the lifetime value of plastic is borne in the first 100 years and 95% of the lifetime value is borne in the first 150 years. This gives the authors confidence in their efforts to provide a conservative estimate of plastic's lifespan since key plastic waste types have life expectancies beyond 150 years. The formula used was the annual cost of plastic produced in 2019 that entered the ocean (LB: 41,897,689,714 , UB:83,795,379,428) divided by the discount rate of 2%.

11 This is based on the authors of this report's estimate of the median minimum lifetime cost of the plastic produced in 2019 being US$3.7 trillion - upper bound being US$4.8 trillion and lower bound being US$2.7 trillion.

12 This is based on the authors of this report's estimate of the median minimum lifetime cost of the plastic produced in 2019 being US$3.7 trillion - upper bound being US$4.8 trillion and lower bound being US$2.7 trillion - and countries' GDP data from Investopedia Silver, Caleb., 2020. The Top 25 Economies in the World. Investopedia. Available at: <https://www.investopedia.com/insights/worlds-top-economies/> [Accessed 18 August 2021].

13 Virgin plastic is the direct output produced from refining a petrochemical feedstock, such as natural gas or crude oil, which has never been used or processed before.

14 See Annex 3: Methodology for an overview of how this figure was calculated. All values provided in 2019 US$.

15 See Annex 3: Methodology for an overview of how this figure was calculated. All values provided in 2019 US$.

16 See Annex 3: Methodology for an overview of how this figure was calculated. All values provided in 2019 US$.

17 See Annex 3: Methodology for an overview of how this figure was calculated. All values provided in 2019 US$.

18 See Annex 3: Methodology for an overview of how this figure was calculated. All values provided in 2019 US$.

19 This is based on i) the authors of this report's estimate of the median projected cost of the plastic produced in 2040 being US$7.1 trillion - upper bound being US$9.3 trillion and lower bound being US$4.9 trillion; ii) global spending on health in 2018 being US$8.3 trillion as per the World Health Organization, 2020. *Global spending on health: Weathering the storm*.; and iii) GDPs of Germany (US$3.86 trillion), Canada (US$1.74 trillion), and Australia (US$1.4 trillion), sum up to US$7 trillion as per data from Investopedia Silver, Caleb., 2020. The Top 25 Economies in the World. Investopedia. Available at: <https://www.investopedia.com/insights/worlds-top-economies/> [Accessed 18 August 2021].

20 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

21 This is based on limiting warming to under 1.5 C; the Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

22 Ellen MacArthur Foundation, 2021. Policies for a Circular Economy for Plastic: *The Ellen MacArthur Foundation's perspective on a UN treaty to address plastic pollution*.

23 World Economic Forum, 2016. *The New Plastics Economy: Rethinking the future of plastics*.

24 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

25 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

26 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.

27 UN Environment, 2017. *Combating Marine Plastic Litter and Microplastics: An Assessment of the Effectiveness of Relevant International, Regional and Subregional Governance Strategies and Approaches*.

28 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.

29 WWF (n.d.), *Ghost Gear- The silent predator*, viewed 6 August 2021, <https://wwf.panda.org/act/take_action/plastics_campaign_page/>.

30 WWF (n.d.). Global Plastic Navigator [Online]. Available at: https://plasticnavigator.wwf.de/#/en/stories/?st=0&ch=0&layers=surface-concentration (Accessed: 12 August 2021).

31 Risko *et al.* (2020) "Cost-effectiveness and return on investment of protecting health workers in low- and middle-income countries during the COVID-19 pandemic", *PLoS ONE*, 15(10), pp 1-10.

32 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).

33 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.

34 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).

35 UNEP, 2018. *Single-use plastics: A Roadmap for Sustainability*.

36 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

37 Calculations based on a 21.59 cm long straw, with an assumption that the circumference of the world is 40,075 km.

38 This proportion refers only do municipal solid and microplastic waste as per the Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

39 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

40 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

41 CIEL, 2019. *Plastic and Health: The Hidden Costs of a Plastic Planet*.

42 Deloitte, 2019. *Price Tag of Plastic Pollution*.

43 Babbage, N. (2019) "New publication out: Consumer response to plastic waste" *Kantar*, 9 October. Results based on global survey of over 65k people in 24 countries.

44 Ryan, P.G. (2015) "A Brief History of Marine Litter Research". In: Bergmann, M., Gutow, L. and Klages, M. (eds), Marine Anthropogenic Litter. Springer, Cham. https://doi.org/10.1007/978-3-319-16510-3.

45 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.

46 Lebanc, R., (2021) "The Decomposition of Waste in Landfills", The Balance Small Business, January 16, Accessed 20 August 2021, <https://www.thebalancesmb.com/how-long-does-it-take-garbage-to-decompose-2878033>.

47 Nauendorf, A. et al., (2016) "Microbial colonization and degradation of polyethylene and biodegradable plastic bags in temperate fine-grained organic-rich marine sediments", Marine Pollution Bulletin, 103, pp 168-178.

48 See Annex 3: Methodology for an overview of how these costs were estimated. All values provided in 2019 US$.

49 This is based on the authors of this report's estimate of the median minimum lifetime cost of the plastic produced in 2019 being US$3.7 trillion - upper bound being US$4.8 trillion and lower bound being US$2.7 trillion - and countries' GDP data from Investopedia Silver, Caleb., 2020. The Top 25 Economies in the World. Investopedia. Available at: <https://www.investopedia.com/insights/worlds-top-economies/> [Accessed 18 August 2021].

50 This is based on the authors of this report's estimate of the median minimum lifetime cost of the plastic produced in 2019 being US$3.7 trillion - upper bound being U $4.8 trillion and lower bound being US$2.7 trillion - and countries' GDP data from Investopedia Silver, Caleb., 2020. The Top 25 Economies in the World. Investopedia. Available at: <https://www.investopedia.com/insights/worlds-top-economies/> [Accessed 18 August 2021].

51 See Annex 3: Methodology for an overview of how these costs were estimated. All values provided in 2019 US$.

52 Nielsen, T. *et al.* "Politics and the plastic crisis: A review throughout the plastic life cycle", *Wiley Interdisciplinary Reviews: Energy and Environment,* 9(1).

53 This is given that the cost of GHG emissions in 2019 is estimated as US$171 billion as per this report's model (see Annex 3: Methodology for more detail on how this figure was estimated) and global spending on the energy transition globally in 2020 is US$501.3 billion as per Bloomberg; BloombergNEF, 2021. "Energy Transition Investment Trends Tracking global investment in the low-carbon energy transition." [PowerPoint presentation] 19 January. The authors of this report converted this value into 2019 dollars to give ~US$469 billion.

54 Zheng, J. and Suh, S. (2019) "Strategies to reduce the global carbon footprint of plastics", *Nature Climate Change*, 9, pp 374-378. 1.8Gt is the estimate of emissions excluding the displacement of virgin polymer production from recycling.

55 UNEP, 2020. *Emissions Gap Report 2020*.

56 This is based on GHG emissions excluding land-use change. Plastic would be exceeded by China, United States of America, India, and the Russian Federation. EU27 +UK would also exceed plastic but this report excluded them from the ranking as they are a group of countries not a singular country; UNEP, 2020. Emissions Gap Report 2020.

57 NASA. (n.d.) *The Effects of Climate Change*, viewed 13 August 2021, < https://climate.nasa.gov/effects/>.

58 European Commission. (n.d.) *Climate Change consequences*.

59 WWF. (n.d.) *Effects of Climate Change*, viewed 13 August 2021, < https://www.worldwildlife.org/threats/effects-of-climate-change>.

60 National Resources Defence Council, 2008. *The Cost of Climate Change: What We'll Pay if Global Warming Continues Unchecked*.

61 Zheng, J. and Suh, S. (2019) "Strategies to reduce the global carbon footprint of plastics", *Nature Climate Change*, 9, pp 374-378.

62 Zheng, J. and Suh, S. (2019) "Strategies to reduce the global carbon footprint of plastics", *Nature Climate Change*, 9, pp 374-378.

63 CIEL, 2019. *Plastic and Climate: The Hidden Costs of a Plastic Planet*.

64 Zheng, J. and Suh, S. (2019) "Strategies to reduce the global carbon footprint of plastics", *Nature Climate Change*, 9, pp 374-378.

65 Reyna-Bensusan, N. *et al.* (2019) "Experimental measurements of black carbon emission factors to estimate the global impact of uncontrolled burning of waste", *Atmospheric Environment*, 213, pp 629-639.

66 Royer, S.J, *et al.* (2018) "Production of Methane and Ethylene from Plastic in the Environment", *PLoS ONE*, 13(8), pp 1-13.

67 See Annex 3: Methodology for an overview of how these costs were estimated. All values provided in 2019 US$.

68 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.

69 Based on data collected by the Pew Charitable Trusts and SYSTEMIQ; the Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave* (see Annex 3: Methodology for more detail on how these figures were calculated. All values provided in 2019 US$).

70 Brooks, A.L., Wang, S. and Jambeck, J. R. (2018). "The Chinese import ban and its impact on global plastic waste trade", *Science Advances*, 4(6), pp 1-7.

71 McCormick, E. *et al.* (2019) "Where does your plastic go? Global investigation reveals America's dirty secret", *The Guardian*, 17 June.

72 This calculation is based on US plastic waste per capita of 0.1062 tonnes as per Holden, E. "US produces far more waste and recycles far less of it than other developed countries", The Guardian, 3 July, accessed 6 August, <https://www.theguardian.com/us-news/2019/jul/02/us-plastic-waste-recycling>, and average household size of 2.53 as per Statista, (2020), "Average number of people per household in the United States from 1960 to 2020", viewed 6 August 2021, <https://www.statista.com/statistics/183648/average-size-of-households-in-the-us/>. Multiplying per capita plastic waste by average household size results in plastic waste per household (0.269 tonnes). Dividing 83,000 tonnes of plastic waste exported to Vietnam divided by plastic waste per household results in approximately 300,000 US households.

73 IUCN-EA-QUANTIS, 2020. *National Guidance for plastic pollution hotspotting and shaping action, Country report: Vietnam*.

74 Gaia, 2019. *Discarded: Communities on the Frontlines of the Global Plastic Crisis*.

75 Tabuchi, H. and Corkery, M. (2019) "Countries Tried to Curb Trade in Plastic Waste. The U.S. Is Shipping More", *The New York Times*, 12 March.

76 Interpol, 2018. *Strategic Analysis Report: Emerging criminal trends in the global plastic waste market since January 2018*.

77 See Annex 3: Methodology for an overview of how these costs were estimated. All values provided in 2019 US$.

78 Barbier E.B. (2017) "Marine ecosystem services", *Current Biology*, 27(11).

79 See Annex 3: Methodology for an overview of how these costs were estimated. All values provided in 2019 US$.

80 Costanza *et al.* (2014) "Changes in the global value of ecosystem services", *Global Environmental Change*, 26, pp 152-158.

81 The exception is algae and bacteria. Plastic increases the range of habitats available for colonization and enables the spread of these species to new areas, thus increasing their range and abundance. Beaumont, N.J. *et al.* "Global ecological, social and economic impacts of marine plastic", Marine Pollution Bulletin, 142, pp 189-195.

82 Beaumont, N.J. *et al.* (2019) "Global ecological, social and economic impacts of marine plastic", Marine Pollution Bulletin, 142, pp 189-195.

83 Based on Beaumont, N.J. *et al.* (2019) "Global ecological, social and economic impacts of marine plastic", *Marine Pollution Bulletin*, 142, pp 189-195.

84 Beaumont, N.J. *et al.* (2019) "Global ecological, social and economic impacts of marine plastic", *Marine Pollution Bulletin*, 142, pp 189-195.

85 The authors of this report have calculated this by using a perpetual net present value (NPV) formula (see Annex 3: Methodology for more detail into how the authors obtained this estimate).

86 This is based on the authors of this report's estimate of the median minimum ecosystem service cost of US$3.1 trillion - upper bound being US$4.2 trillion and lower bound being US$2.1 trillion - and global spending on education in 2019 was US$5.0 trillion as per the World Bank, 2021. *Education Finance Watch (figure 1)*.

87 Watson, A.J. *et al.* (2020) "Revised estimates of ocean-atmosphere CO^2 flux are consistent with ocean carbon inventory", *Nature Communications*, 11(4422), pp 1-6.

88 Basu, S. and Mackey, K.R.M. (2018) "Phytoplankton as Key Mediators of the Biological Carbon Pump: Their Responses to a Changing Climate", *Sustainability*, 10(3).

89 Desforges JP.W., Galbraith, M. and Ross, P.S. (2015) "Ingestion of Microplastics by Zooplankton in the Northeast Pacific Ocean", *Archives of Environmental Contamination and Toxicology*, 69, pp 320-330.

90 Wieczorek, A.M. *et al.* (2019). "Microplastic Ingestion by Gelatinous Zooplankton May Lower Efficiency of the Biological Pump", *Environmental Science & Technology*, 53(9), pp 5387-5395.

91 Cole, M. *et al.* (2015). "The Impact of Polystyrene Microplastics on Feeding, Function and Fecundity in the Marine Copepod Calanus helgolandicus", *Environmental Science & Technology*, 49(2), pp 1130-1137.

92 Cole, M. *et al.* (2013). "Microplastic Ingestion by Zooplankton", *Environmental Science & Technology*, 47(12), pp 6646-6655.

93 Deloitte, 2019. *Price Tag of Plastic Pollution*.

94 Deloitte, 2019. *Price Tag of Plastic Pollution*.

95 Beaumont, N.J. *et al.* (2019) 'Global ecological, social and economic impacts of marine plastic', *Marine Pollution Bulletin*, 142, pp 189-195.

96 Deloitte, 2019. *Price Tag of Plastic Pollution*.

97 Deloitte, 2019. *Price Tag of Plastic Pollution*.

98 Deloitte, 2019. *Price Tag of Plastic Pollution*.

99 Deloitte, 2019. *Price Tag of Plastic Pollution*.

100 WWF, 2020. *Stop Ghost Gear: The most deadly form of marine plastic debris*.

101 Gall, S.C. and Thompson, R.C. (2015). "The impact of debris on marine life", *Marine Pollution Bulletin*, 92(1-2), pp 170-179.

102 WWF, 2020. *Stop Ghost Gear: The most deadly form of marine plastic debris*.

103 Seal haul-out sites are locations on land where seals come ashore to rest, moult or breed.

104 Allen, R., Jarvis, D., Sayer, S. and Mills, C. (2012). "Entanglement of grey seals Halichoerus grypus at a haul out site in Cornwall, UK.", *Marine pollution bulletin*, 64 (12), pp 2815-2819.

105 Allen, R., Jarvis, D., Sayer, S. and Mills, C. (2012). "Entanglement of grey seals Halichoerus grypus at a haul out site in Cornwall, UK.", *Marine pollution bulletin*, 64 (12), pp 2815-2819.

106 Karamanlidis, A.A. *et al.* (2008). "Assessing accidental entanglement as a threat to the Mediterranean monk seal Monachus monachus", *Endangered Species Research*, 5(2), p205-213.

107 NOAA, 2019. *Marine Debris Impacts on Coastal and Benthic Habitats*.

108 Valderrama Ballesteros, L., Matthews, J.L. and Hoeksema, B.W. (2018). "Pollution and coral damage caused by derelict fishing gear on coral reefs around Koh Tao, Gulf of Thailand." *Marine Pollution Bulletin*, 135, pp 1107-1116. https://doi.org/10.1016/j.marpolbul.2018.08.033.

109 Airoldi, L., Balata, D. and Beck, M.W. (2008). "The Gray Zone: Relationships between habitat loss and marine diversity and their applications in conservation", *Journal of Experimental Marine Biology and Ecology*, (366), pp 8-15.

110 Richardson, K. *et al.* (2019). "Building evidence around ghost gear: Global trends and analysis for sustainable solutions at scale", Marine Pollution Bulletin, (138), pp 222-229.

111 UNEP, 2009. *Abandoned, lost or*

otherwise discarded fishing gear.
112 Cho, D.O. (2004). "Case Study of derelict fishing gear in Republic of Korea", paper presented to APEC Seminar on Derelict Fishing Gear and Related Marine Debris, Honolulu, Hawaii, USA, 13–16 January.
113 CIEL, 2019. *Plastic and Health: The Hidden Costs of a Plastic Planet*.
114 CIEL, 2019. *Plastic and Health: The Hidden Costs of a Plastic Planet*.
115 Jemielita, T. (2015). "Unconventional Gas and Oil Drilling Is Associated with Increased Hospital Utilization Rates", *PLoS ONE*, 10(7), pp 1-18.
116 CIEL, 2019. *Plastic and Health: The Hidden Costs of a Plastic Planet*.
117 Tait, P.W. *et al.* (2019). "The health impacts of waste incineration: a systematic review", *Australian and New Zealand Journal of Public Health*, 44(1), pp 1-9.
118 Tait, P.W. *et al.* (2019). "The health impacts of waste incineration: a systematic review", *Australian and New Zealand Journal of Public Health*, 44(1), pp 1-9.
119 White, S.S. and Birnbaum, L.S. (2010). "An Overview of the Effects of Dioxins and Dioxin-like Compounds on Vertebrates, as Documented in Human and Ecological Epidemiology", *J Environ Sci Health C Environ Carcinog Ecotoxicol Rev*, 27(4), pp 197–211.
120 Zhang, Y. *et al.* (2016). "Leaching Characteristics of Trace Elements from Municipal Solid Waste Incineration Fly Ash", *Geotechnical Special Publication*, 273, pp 168-178.
121 Zhang, Q. *et al.* (2020). "A Review of Microplastics in Table Salt, Drinking Water, and Air: Direct Human Exposure", *Environmental Science & Technology*, 54(7), pp 3740-3751.
122 Masantes, M.D., Consea, J.A. and Fullana, A. (2020) "Microplastics in Honey, Beer, Milk and Refreshments in Ecuador as Emerging Contaminants", *Sustainability*, 12(14), pp 1-17.
123 Hossain, M.S. *et al.* (2020). "Microplastic contamination in Penaeid shrimp from the Northern Bay of Bengal", *Chemosphere*, 238.
124 Schwabl, P. *et al.* (2019) "Detection of Various Microplastics in Human Stool: A Prospective Case Series", *Annals of Internal Medicine*, 171(7).
125 Ragusa, A. *et al.* (2021) "Plasticenta: First evidence of microplastics in human placenta", *Environment International*, 146.
126 CIEL, 2019. *Plastic and Health: The Hidden Costs of a Plastic Planet*.
127 WHO, 2019. *Microplastics in Drinking Water*.
128 Prata, J.C. *et al.* (2020) "Environmental exposure to microplastics: An overview on possible human health effects", *Science of the Total Environment*, 702.
129 World Health Organization, *2019. Microplastics in drinking-water*.
130 Bucca, K., Tulio, M. and Rochman, C.M. (2019) "What is known and unknown about the effects of plastic pollution: A meta-analysis and systematic review", *Ecological Applications*, 30(2).
131 Zhao, S., Zhu, L. and Li, Daoji. (2016) "Microscopic anthropogenic litter in terrestrial birds from Shanghai, China: Not only plastics but also natural fibers", *Science of the Total Environment*, 550, pp 1110-1115.
132 Omidi, A., H. Naeemipoor, and M. Hosseini. (2012) "Plastic debris in the digestive tract of sheep and goats: An increasing environmental contamination in Birjand, Iran", *Bulletin of Environmental Contamination and Toxicology*, 88(5), pp 691-694.
133 Maclvor, J.S. and Moore, A. (2013) "Bees collect polyurethane and polyethylene plastics as novel nest materials", *Ecosphere*, 4(12).
134 Piehl, S. *et al.* (2018) "Identification and quantification of macro-and microplastics on an agricultural farmland", *Scientific reports*, 8(1), pp 1-9.
135 Sanders L.C. and Lord E.M. (1989) "Directed movement of latex particles in the gynoecia of three species of flowering plants", *Science*, 243(4898), pp 1606-8.
136 Boots, B., Russell, C.W. and Green, D.S. (2019) "Effects of Microplastics in Soil Ecosystems: Above and Below Ground", *Environmental Science and Technology*, 53(19).
137 Steinmetz, Z. *et al.* (2016) "Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation?", *Science of the Total Environment*, 550, pp 690-705.
138 Tishman Environment and Design Center, 2019. *U.S. Municipal Solid Waste Incinerators: An Industry in Decline*.
139 Fernández-Llamazares, A. *et al.* (2019) "A State-of-the-Art Review of Indigenous Peoples and Environmental Pollution", *Integrated Environmental Assessment and Management*, 16(3), pp 324-341.
140 UNEP, 2021. *Neglected: Environmental Justice Impacts of Marine Litter and Plastic Pollution*.
141 CIEL, 2019. *Plastic and Health: The Hidden Cost of a Plastic Planet*.
142 Zhao, Q. *et al.* (2016) "The Effect of the Nengda Incineration Plant on Residential Property Values in Hangzhou, China", *Journal of Real Estate Literature*, 24(1), pp 85-102.
143 Auler, F., Nakashima, A.T. and Cuman, R.K. (2013) "Health Conditions of Recyclable Waste Pickers", *Journal of Community Health*, 39(1).
144 Velis, C.A. and Cook, E. (2021) "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 & Technology*, 55(11), pp 7186-7207.
145 Zolnikov, T.R. *et al.* (2021) "A systematic review on informal waste picking: Occupational hazards and health outcomes", *Waste Management*, 126, pp 291-308.
146 Kistan, J. *et al.* (2020) "Health care access of informal waste recyclers in Johannesburg, South Africa", *PLoS One*, 15(7).
147 International Monetary Fund. (2017) "The Effects of Weather Shocks on Economic Activity: How Can Low-Income Countries Cope?" in *Seeking Sustainable Growth: Short-Term Recovery, Long-Term Challenges,* pp 117-184.
148 International Monetary Fund. (2017) "The Effects of Weather Shocks on Economic Activity: How Can Low-Income Countries Cope?" in *Seeking Sustainable Growth: Short-Term Recovery, Long-Term Challenges,* pp 117-184.
149 Islam S.N. and Winkel, J. (2017) Climate Change and Social Inequality. UN Department of Economic and Social Affairs DESA Working Paper No. 152. Available at: https://www.un.org/esa/desa/papers/2017/wp152_2017.pdf
150 See Annex 3: Methodology for an overview of how this figure was calculated. All values provided in 2019 US$.
151 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
152 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
153 Walpole, S.C. *et al.* (2012) "The weight of nations: an estimation of adult human biomass", *BMC Public Health,* 12(439).
154 See Annex 3: Methodology for more details on how these figures were estimated. All values provided in 2019 US$.
155 This is based on the authors of this report's estimate of the median projected cost of the plastic produced in 2040 being US$7.1 trillion - upper bound being US$9.3 trillion and lower bound being US$4.9 trillion - and that global spending on health was US$8.3 trillion in 2018 as per the World Health Organization, 2020. Global spending on health: Weathering the storm.
156 This is based on the authors of this report's estimate of the median projected societal lifetime cost of the plastic produced in 2040 being US$7.1 trillion - upper bound being US$9.3 trillion and lower bound being US$4.9 trillion - and that the GDPs of Germany (US$3.86 trillion), Canada (US$1.74 trillion), and Australia (US$1.4 trillion), sum up to US$7 trillion as per data from Investopedia Silver, Caleb., 2020. The Top 25 Economies in the World. Investopedia. Available at: <https://www.investopedia.com/insights/worlds-top-economies/> [Accessed 18 August 2021].
157 This is based on the authors of this report's estimate of the median projected cost of the plastic produced in 2040 being US$7.1 trillion - upper bound being US$9.3 trillion and lower bound being US$4.9trillion - and that global spending on health was US$8.3 trillion in 2018 as per the World Health Organization, 2020. *Global spending on health: Weathering the storm.*
158 This is based on the authors of this report's estimate of the median projected cost of the plastic produced in 2040 being US$7.1 trillion - upper bound being US$9.3 trillion and lower bound being US$4.9 trillion - and that and that the GDPs of Germany (US$3.86 trillion), Canada (US$1.74 trillion), and Australia (US$1.4 trillion), sum up to US$7 trillion as per data from Investopedia Silver, Caleb., 2020. The Top 25 Economies in the World. Investopedia. Available at: <https://www.investopedia.com/insights/worlds-top-economies/> [Accessed 18 August 2021].
159 This is based on limiting warming to under 1.5 C.
160 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
161 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
162 CIEL, 2019. *Plastic and Climate: The Hidden Costs of a Plastic Planet*.
163 European Commission, 2020. *Draft budget 2020: Statement of Estimates*.
164 Ellen MacArthur Foundation, 2021. *Policies for a Circular Economy for Plastic: The Ellen MacArthur Foundation's perspective on a UN treaty to address plastic pollution*.
165 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
166 Tyres, textiles, personal care products and production pellets. Source: the Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
167 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
168 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
169 Ellen MacArthur Foundation, 2017. *The New Plastics Economy: Rethinking The Future Of Plastics & Catalysing Action*.
170 Ellen MacArthur Foundation, 2020. *Perspective on 'Breaking the Plastic Wave' study: The Circular Economy Solution to Plastic Pollution*.
171 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave*.
172 Backhaus, T. and Wagner, M. (2019) 'Microplastics in the Environment: Much Ado about Nothing? A Debate', *Global Challenges*, 4(1900022).
173 Ellen MacArthur Foundation, 2021. *Policies for a Circular Economy for Plastic: The Ellen MacArthur Foundation's perspective on a UN treaty to address plastic pollution*.
174 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.
175 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.
176 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.
177 Ellen MacArthur Foundation, 2021. *Policies for a Circular Economy for Plastic: The Ellen MacArthur Foundation's perspective on a UN treaty to address plastic pollution*.
178 Parker, L. (2021) "Global treaty to regulate plastic pollution gains momentum", *National Geographic (Environment)*, 8 June. Available at: https://www.nationalgeographic.co.uk/environment-and-conservation/2021/06/global-treaty-to-regulate-plastic-pollution-gains-momentum.
179 Parker, L. (2021) "Global treaty to regulate plastic pollution gains momentum", *National Geographic (Environment)*, 8 June. Available at: https://www.nationalgeographic.co.uk/environment-and-conservation/2021/06/global-treaty-to-regulate-plastic-pollution-gains-momentum.
180 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.
181 UNEP-WCMC, 2017. *Governance of areas beyond national jurisdiction for biodiversity conservation and sustainable use: Institutional arrangements and cross-sectoral cooperation in the Western Indian Ocean and the South East Pacific*.
182 UN Environment, 2017. *Combating Marine Plastic Litter and Microplastics: An Assessment of the Effectiveness of Relevant International, Regional and Subregional Governance Strategies and Approaches*.
183 UNEP, 2020. *Summary of the analysis of the effectiveness of existing and potential response options and activities on marine litter and microplastics at all levels to determine the contribution in solving the global problem*.
184 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.
185 WWF, 2020. *The Business Case for a UN Treaty on Plastic Pollution*.
186 Soares, J. *et al.* (2021) 'Public views on plastic pollution: Knowledge, perceived impacts, and pro-environmental behaviours', *Journal of Hazardous Materials*, 412.
187 SEA Circular, 2020. *Perceptions on Plastic Waste*.
188 WWF (n.d.), *Ghost Gear – the silent predator*, viewed 6 August 2021, <https://wwf.panda.org/act/take_action/plastics_campaign_page/>.
189 WWF (n.d.). Global Plastic Navigator [Online]. Available at: https://plasticnavigator.wwf.de/#/en/stories/?st=0&ch=0&layers=surface-concentration (Accessed: 12 August 2021).
190 This estimate is not a holistic and bottom-up estimate of the costs incurred by South Africa, rather it is a pro-rata of the global cost estimate based on South Africa's share of global waste generation from Our World in Data figures; Our World in Data (n.d.), 'Plastic waste generation, 2010', viewed 6 August 2021, <https://ourworldindata.org/grapher/plastic-waste-generation-total?tab=chart>. Total national plastic waste generation was calculated by Our World in Data based on per capita plastic waste generation data published in Jambeck, J. R. *et al.* (2015). 'Plastic waste inputs from land into the ocean'. *Science*, 347(6223), pp 768-771 and total population data published in the World Bank, World Development Indicators (available at: https://datacatalog.worldbank.org/dataset/world-development-indicators).
191 IUCN-EA-QUANTIS, 2020. *National Guidance for plastic pollution hotspotting and shaping action*.
192 Rodseth C., Notten P. and H. von Blottniz, (2020) "A revised approach for estimating informally disposed domestic waste in rural versus urban South Africa and implications for waste management", *South African Journal of Science*, 116, pp 1–6.
193 IUCN-EA-QUANTIS, 2020. *National Guidance for plastic pollution hotspotting and shaping action*.
194 Ryan, P.G. (2020) "The transport and fate of marine plastics in South Africa and adjacent oceans", *South African Journal of Science*, 116(5/6).
195 Chitaka, T.Y. and von Blottnitz, H. (2018) "Accumulation and characteristics of plastic debris along five beaches in Cape Town", *Marine Pollution Bulletin*, 138, pp 451-457.
196 South African Department of Tourism, 2017. *South Africa: State of tourism report, 2016/17*.
197 Balance, A., Ryan, P.G. and Turipe, J. (2000) "How much is a clean beach worth? The impact of litter on beach users in the Cape Peninsula, South Africa", *South African Journal of Science*, 96(5), pp 210-213.
198 South African Government 2014, Fisheries, Department of Agriculture, Forestry and Fisheries (South Africa), viewed 3 August 2021.
199 Clark, B.M. *et al.* (2002) "Identification of subsistence fishers, fishing areas, resource use and activities along the South African coast", *South African Journal of Marine Science*, 24, pp 425-437.
200 WWF, 2020. *Plastics: Facts and futures. Moving beyond pollution management towards a circular plastics economy in South Africa*.
201 South Africa Department of Environmental Affairs, 2018. *State of Waste Report South Africa*.
202 Von Blottnitz, H., Chitaka, T. and C. Rodseth. (2018). "South Africa beats Europe at plastics recycling, but also is a top 20 ocean polluter. Really?" epse.uct.ac.za/sites/default/files/image_tool/images/363/Publications/SA%20plastics%20MFA%20commentary%20by%20E%26PSE%20rev1.pdf.
203 Center for International Environmental Law, 2019. *Plastic & Health: The Hidden Costs of a Plastic Planet*.
204 South African Government, 2021. *Forestry, Fisheries and the Environment on amendments to plastic bag regulations*.
205 South African Government, 2020. *National Environmental Management: Waste Act (59/2008): Regulations regarding extended producer responsibility*.
206 African Ministerial Conference on the Environment, 2019. *Draft Durban Declaration on taking action for environmental sustainability and prosperity in Africa*.
207 African Ministerial Conference on the Environment, 2019. *Draft Durban Declaration on taking action for environmental sustainability and prosperity in Africa*.
208 Vlavianos, C. (2021) "Thousands of South Africans call for stricter plastic regulations from the DEFF Director General", Greenpeace, 13 April. Available at: https://www.greenpeace.org/africa/en/press/13506/thousands-of-south-africans-call-for-stricter-plastic-regulations-from-the-deff-director-general/.
209 Plastic Pollution Treaty, (n.d.). *The business call for a UN Treaty on plastic pollution*.
210 Australian Government, 2021. *National Plastics Plan 2021*.
211 Australian Government Commonwealth Scientific and Industrial Research Organisation, 2021. *A circular economy roadmap for plastics, tyres, glass and paper in Australia*.
212 This estimate is not a holistic and bottom-up estimate of the costs incurred by Australia, rather it is a pro-rata of the global cost estimate based on Australia's share of global waste generation from Our World in Data figures; Our World in Data (n.d.), 'Plastic waste generation, 2010', viewed 6 August 2021, <https://ourworldindata.org/grapher/plastic-waste-generation-total?tab=chart>. Total national plastic waste generation was calculated by Our World in Data based on per capita plastic waste generation data published in Jambeck, J. R. *et al.* (2015). Plastic waste inputs from land into the ocean. *Science*, 347(6223), pp 768-771 and total population data published in the World Bank, World Development Indicators (available at: https://datacatalog.worldbank.org/dataset/world-development-indicators).
IUCN-EA-QUANTIS, 2020. National Guidance for plastic pollution hotspotting and shaping action.
213 Australian Government, 2021. *National Plastics Plan 2021*.
214 O'Farrell, K., (2020). *2018–19 Australian Plastics Recycling Survey National report*. Envisageworks, Melbourne: Australian Government Department of Agriculture, Water and the Environment.
215 World Wide Fund for Nature Australia and Boston Consulting Group, 2020. *Plastics Revolution to reality - A roadmap to halve Australia's single-use plastic litter*.
216 Charles, D., Kimman, L. and Saran, N. (2021) 'The plastic waste-makers index', Minderoo Foundation.
217 Australian Government, 2021. *National Plastics Plan 2021*.
218 Australian Packaging Covenant Organization, 2020. *Australian packaging*

consumption and recycling data 2018/19.
219 World Wide Fund for Nature Australia and Boston Consulting Group, 2020. *Plastics Revolution to reality - A roadmap to halve Australia's single-use plastic litter.*
220 Given the cost estimate is a pro-rata estimate based on a global total, the authors do not include the APEC figures as part of the cost estimate and rather include them here to show the specific costs for industries for Australia. Source: APEC, 2020. *Update of 2009 APEC Report on Economic Costs of Marine Debris to APEC Economies.*
221 APEC, 2020. *Update of 2009 APEC Report on Economic Costs of Marine Debris to APEC Economies.*
222 Australian Government Commonwealth Scientific and Industrial Research Organisation, 2015. *Inquiry into the Threat of Marine Plastic Pollution in Australia and Australian Waters.*
223 Wilcox, C. *et al.* (2018) "A quantitative analysis linking sea turtle mortality and plastic debris ingestion", *Scientific Reports*, 8(1).
224 Acampora, H. *et al.* (2013). "Comparing plastic ingestion between juvenile and adult stranded Short-tailed Shearwaters (Puffinus tenuirostris) in Eastern Australia", *Marine Pollution Bulletin*, 78(1-2).
225 Hardesty, B.D. *et al.* (2013). "Understanding the effects of marine debris on wildlife", Commonwealth Scientific and Industrial Research Organisation.
226 Department of Agriculture, Water and the Environment, (2021) "Environment Ministers Meeting 1Agreed Communique", Australian Government, 15 April, viewed 6 August 2021, <https://www.awe.gov.au/sites/default/files/2021-04/emm-1-agreed-communique.pdf>.
227 From July 1, 2021 only plastics that have been either "sorted into single resin or polymer type" or "processed with other materials into processed engineered fuel" may be exported; from July 1, 2022 only plastics "that have been sorted into single resin or polymer type and/or have been further processed into, e.g. flakes or pellets" will be able to be exported. Source: *Recycling and Waste Reduction Act 2020.* Available at: https://www.legislation.gov.au/Details/C2020A00119.
228 Australian Government, 2021. *National Plastics Plan 2021.*
229 Australian Government, n.b.d. *Australian Recycling Investment Fund.*
230 Australian Government, 2020. *Budget 2020-21: Supporting healthy oceans.*
231 EIA, 2020. *Plastic Pollution Prevention in Pacific Island Countries: Gap analysis of current legislation, policies and plans.*
232 Commonwealth Scientific and Industrial Research Organisation, 2021. *National Circular economy roadmap for plastics, glass, paper and tyres. Pathways for unlocking future growth opportunities for Australia.*
233 Hardesty, B, and Wilcox, C. (2011). "Understanding the types, sources and at-sea distribution of marine debris in Australian waters", Commonwealth Scientific and Industrial Research Organisation.
234 Jambeck, J.R. *et al.* (2015) "Plastic waste inputs from land into the ocean", *Science*, 347(6223), pp768-771.
235 This estimate is not a holistic and bottom-up estimate of the costs incurred by Japan, rather it is a pro-rata of the global cost estimate based on Japan's share of global waste generation from Our World in Data figures; Our World in Data (n.d.), "Plastic waste generation, 2010", viewed 6 August 2021, <https://ourworldindata.org/grapher/plastic-waste-generation-total?tab=chart>. Total national plastic waste generation was calculated by Our World in Data based on per capita plastic waste generation data published in Jambeck, J. R. *et al.* (2015). Plastic waste inputs from land into the ocean. *Science*, 347(6223), pp 768-771. and total population data published in the World Bank, World Development Indicators (available at: https://datacatalog.worldbank.org/dataset/world-development-indicators).
IUCN-EA-QUANTIS, 2020. National Guidance for plastic pollution hotspotting and shaping action.
236 Ministry of the Environment Government of Japan (2021), "The situation of plastics both within and outside Japan" available at: https://www.env.go.jp/council/03recycle/20210128_s7.pdf.
237 UNEP. (2018). *Single-use plastics: A roadmap for sustainability.*
238 Isobe, A. *et al.* (2015) 'East Asian seas: A hot spot of pelagic microplastics', *Marine Pollution Bulletin*, 101(2), pp 618-623.
239 Kuroda, M. *et al.* (2020) 'The current state of marine debris on the seafloor in offshore area around Japan', *Marine Pollution Bulletin*, 161(A).
240 World Travel & Tourism Council. (2021). *Travel & Tourism Economic Impact 2021.*
241 Tanaka, K. and Takada, H. (2016) 'Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters', *Scientific Reports*, 6(1).
242 OECD, 2021. *Fisheries and Aquaculture in Japan.*
243 Japanese Government, 2000. *The Basic Act for Establishing a Sound Material-Cycle Society.*
244 United Nations, 2018. *The state of plastics: World Environment Day Outlook 2018.*
245 Plastic Waste Management Institute, 2019. *An Introduction to Plastic Recycling.*
246 Plastic Waste Management Institute, 2019. *An Introduction to Plastic Recycling.*
247 Osaka Blue Ocean Vision (2020). *About us*, viewed 2 August 2021.
248 EIA, 2021. *Pressure on Japan grows as poll shows public wants more action on plastic pollution ahead of G7.*
249 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave.*
250 Deloitte, 2015. *Increased EU Plastics Recycling Targets: Environmental, Economic and Social Impact Assessment Final Report.*
251 Carbon Tracker, 2020. *The Future's Not in Plastics.*
252 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) 'Production, use, and fate of all plastics ever made', *Science Advances*, 3(7).
253 Drupp, M.A. *et al.* (2018) "Discounting Disentangled", *American Economic Journal: Economic Policy*, 10(4), pp 109-34.
254 Beaumont N.J. *et al.* (2019) "Global ecological, social and economic impacts of marine plastic", *Marine Pollution Bulletin*, 142, pp 189-195.
255 Costanza, R. *et al.* (2014) "Changes in the global value of ecosystem services", *Global Environmental Change*, 26(1), pp 152-158.
256 Jambeck, J.R. *et al.* (2015) "Plastic waste inputs from land into the ocean", *Science*, 347(6223), pp 768-771.
257 Jang, Y.C. *et al.* (2015) "Estimating the Global Inflow and Stock of Plastic Marine Debris Using Material Flow Analysis: A Preliminary Approach", *Journal of the Korean Society for Marine Environment & Energy*, 18(4), pp 263-273.
258 McKinsey, 2015. *Stemming the Tide: Land-based Strategies for a Plastic-free Ocean.*
259 Zheng J. and Suh, S. (2019) "Strategies to reduce the global carbon footprint of plastics", *Nature Climate Change*, 9, pp 374-378.
260 Plastics Europe, 2020. *Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data.*
261 Intergovernmental Panel on Climate Change, 2018. *Global Warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.*
262 HDPE price based on Statista, (2020), "Price of high-density polyethylene worldwide from 2017 to 2019 with estimated figures for 2020 to 2022", viewed 10 August 2021, <https://www.statista.com/statistics/1171074/price-high-density-polyethylene-forecast-globally/>.
PET price based on; Statista, (2020), 'Price of polyethylene terephthalate (PET) worldwide from 2017 to 2019 with estimated figures for 2020 to 2022', viewed 10 August 2021, <https://www.statista.com/statistics/1171088/price-polyethylene-terephthalate-forecast-globally/>.
PVC price based on; Statista, (2020), "Price of polyvinyl chloride worldwide from 2017 to 2019 with estimated figures for 2020 to 2022", viewed 10 August 2021, <https://www.statista.com/statistics/1171131/price-polyvinyl-chloride-forecast-globally/>.
PS price based on; Statista, (2020), 'Price of polystyrene (PS) worldwide from 2017 to 2019 with estimated figures for 2020 to 2022', viewed 10 August 2021, <https://www.statista.com/statistics/1171105/price-polystyrene-forecast-globally/>.
PP price based on; Statista, (2020), 'Price of polypropylene worldwide from 2017 to 2021', viewed 10 August 2021, <https://www.statista.com/statistics/1171084/price-polypropylene-forecast-globally/>.
263 Statista, (2019) "Distribution of plastic production worldwide in 2018, by type", viewed 4 August 2021, <https://www.statista.com/statistics/968808/distribution-of-global-plastic-production-by-type/>.
264 Plastics Europe, 2020. *Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data.*
265 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave.*
266 The collection costs were prorated for plastics such that the collection costs account for only the costs attributable to plastic waste and are therefore higher than the collection of other waste streams, such as organic waste. Allocation was done to reflect the relatively higher volume-to-weight ratio that plastic occupies in a collection truck.
267 The Pew Charitable Trusts assumed that all imported waste was formally sorted. Import data was provided only for trade among archetypes with no data provided for intra archetype trade and was based on United Nations Comtrade database for 2018.
268 The sorting costs were prorated for plastics such that the sorting costs account for only the costs attributable to plastic waste and are therefore higher than the sorting of other waste streams, such as organic waste. Allocation was done to reflect the relatively higher volume-to-weight ratio that plastic occupies in a collection truck.
269 Informal collection and sorting were considered as one process that occurs at the same time.
270 The Pew Charitable Trusts assumed no informal collection or dumpsite collection in rural archetypes. This was based on input from the expert panel who said there wasn't enough value/density in the rural waste stream for waste pickers to profit from collection.
271 The informal collection and sorting costs are the sum of the capital expenditure and the operating expenditure of informal collection and sorting processes. Capital expenditure was calculated as: capital expenditures - average annual CAPEX per T, based on total asset cost, capacity, and asset duration, without accounting for financing costs or discounting [Annual CAPEX = Total CAPEX ÷ Asset Capacity ÷ Asset Duration]. Operating expenditure was calculated as: Opex: annual operational expenditures; these include labor, energy, maintenance costs; calculated on a per tonne (metric ton) basis.
272 Net cost per tonne of incineration was calculated using incineration revenues that account for the sale price of the energy generated, based on Kaza *et al.*, 2018, *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*, World Bank Publications, Washington D.C.; and expert panel consensus and incineration costs based on expert panel consensus on data from actual plants. The costs reflect the same operating, safety, and environment standards across all archetypes.
273 Total landfills costs were calculated based on World Bank data and Eunomia data. The costs reflect the capital expenditures and annualised operating expenditures of engineered landfills.
274 Net cost per tonne of closed-loop recycling was calculated using recyclate sale prices for different recyclates based on a composition of high-value plastics (PET, HDPE, and PP) and costs that represent the sum of the capital expenditure and the operating expenditure of closed-loop recycling processes. Both capital and operating expenditures for closed-loop recycling plants were based on the experience and knowledge of an expert panel and confirmed through interviews. The cost of the recyclate sale process was assumed to be a wash and all recycled waste was assumed to be sold.
275 Net cost per tonne of open-loop recycling was calculated using recyclate sale prices for different recyclates based on a composition of high-value plastics (PET, HDPE, and PP) and costs that represent the sum of the capital expenditure and the operating expenditure of open-loop recycling processes. Both capital and operating expenditures for open-loop recycling plants were based on the experience and knowledge of an expert panel and confirmed through interviews. The cost of the recyclate sale process was assumed to be a wash and all recycled waste was assumed to be sold.
276 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).
277 Plastics Europe, 2020. *Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data.*
278 For simplicity we only include the cost of the first waste management stage for the plastic produced in 2019 (for example, we don't include any costs that recycled plastic incurs after it is recycled used and becomes waste again).
279 Costanza, R. *et al.* (2014) "Changes in the global value of ecosystem services", *Global Environmental Change*, 26(1), pp 152-158.
280 Costanza, R. *et al.* (1997) "The value of the world's ecosystem services and natural capital", *Nature*, pp 253–260..
281 Beaumont N.J. *et al.* (2019) "Global ecological, social and economic impacts of marine plastic", *Marine Pollution Bulletin*, 142, pp 189-195.
282 Beaumont N.J. *et al.* (2019) "Global ecological, social and economic impacts of marine plastic", *Marine Pollution Bulletin*, 142, pp 189-195.
283 Beaumont N.J. *et al.* (2019) used the estimate of 4.8-12.7 million metric tonnes of plastic entering the ocean per year provided in Jambeck, J.R. *et al.* (2015) and the figure of 4.2 million tonnes annually in 2013 provided in Jang, Y.C. *et al.* (2015) to estimate 75 million tonnes in 2011, a reduction of 11 tonnes from the 2013 figure. Beaumont N.J. *et al.* (2019) rounded the estimates to try and increase transparency that the figures applied were estimates, not exact numbers.
284 Beaumont N.J. *et al.* (2019) used the figure of 150 million metric tonnes in 2015 included in McKinsey, (2015). *Stemming the Tide: Land-based Strategies for a Plastic-free Ocean* which was considered to be an underestimate. They therefore assumed it was reasonable to use it as an upper bound estimate for 2011.
285 Drupp, M.A. *et al.* (2018) "Discounting Disentangled", *American Economic Journal: Economic Policy*, 10(4), pp 109-34.
286 Plastics Europe, 2020. *Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data.*
287 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).
288 Out of the approximately 20 potential primary microplastic sources, the Pew Charitable Trusts modelled four main sources representing an estimated 75-85% of microplastic pollution: tire abrasion (TWP), pellet loss, textile microfibers and microplastic ingredients in PCP, including the full microsized spectrum of ingredients.
289 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave.*
290 Boucher, J. and Damien, F. (2017) "Primary Microplastics in the Oceans: A Global Evaluation of Sources." *IUCN.*
291 Arcadis, 2012. *Economic assessment of policy measures for the implementation of the Marine Strategy Framework Directive.*
292 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).
293 Beaumont N.J. *et al.* (2019) "Global ecological, social and economic impacts of marine plastic", *Marine Pollution Bulletin*, 142, pp 189-195.
294 The Pew Charitable Trusts and SYSTEMIQ, 2019. *Breaking the Plastic Wave.*
295 This is based on estimated tonnes of lost fishing gear leaking annually as 0.6Mt as per Boucher, J. and Damien, F. (2017) "Primary Microplastics in the Oceans: A Global Evaluation of Sources." *IUCN.* and the estimated proportion of at-sea sources of plastic leakage accounted for by fishing as 65% as per Arcadis, 2012. *Economic assessment of policy measures for the implementation of the Marine Strategy Framework Directive.*
296 Schwarz, A.E *et al.* (2019) "Sources, transport and accumulation of different types of plastic litter in aquatic environments: A review study." *Marine Pollution Bulletin,* 143, pp92-100.
297 Zheng J. and Suh, S. (2019) "Strategies to reduce the global carbon footprint of plastics", *Nature Climate Change*, 9, pp 374-378.
298 Zheng J. and Suh, S. (2019) "Strategies to reduce the global carbon footprint of plastics", *Nature Climate Change*, 9, pp 374-378.
299 CIEL, 2019. *Plastic and Health: The Hidden Costs of a Plastic Planet.*
300 Zheng J. and Suh, S. (2019) "Strategies to reduce the global carbon footprint of plastics", Nature Climate Change, 9, pp 374-378
301 Intergovernmental Panel on Climate Change, 2018. *Global Warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.*
302 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).
303 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).
304 Geyer, R., Jambeck, J.R. and Law, L.L., (2017) "Production, use, and fate of all plastics ever made", *Science Advances*, 3(7).
305 Plastics Europe, 2020. *Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data.*
306 WEF, 2016. *The New Plastics Economy: Rethinking the future of plastics.*
307 International Energy Agency, 2015. *World Energy Outlook 2015.*
308 Plastics Europe, 2020. *Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data.*
309 Drupp, M.A. *et al.* (2018) "Discounting Disentangled", *American Economic Journal: Economic Policy*, 10(4), pp 109-34

OUR MISSION IS TO CONSERVE NATURE AND REDUCE THE MOST PRESSING THREATS TO THE DIVERSITY OF LIFE ON EARTH.

WWF

Working to sustain the natural world for the benefit of people and wildlife.

together possible™ panda.org

© 2021
Paper 100% recycled

WWF, Rue Mauverney 28, 1196 Gland, Switzerland. Tel. +41 22 364 9111 CH-550.0.128.920-7

For contact details and further information, please visit our international website at www.panda.org