THE PRICE OF PLASTIC POLLUTION

Social Costs and Corporate Liabilities

MINDEROO FOUNDATION

About

Minderoo Foundation

Established by Dr Andrew Forrest AO and Nicola Forrest AO in 2001, Minderoo Foundation is proudly Australian, and one of Asia Pacific's largest philanthropic organisations, with AU$2 billion committed to a range of global initiatives.

The Price of Plastic Pollution: Social Costs and Corporate Liabilities is a project of Minderoo's Plastics initiative, which aims to create a world without plastic pollution. A critical step towards this goal is to bring greater transparency to the plastics supply chain – to better understand its material and financial flows, its environmental impacts, the commitments its companies have made to sustainability, and the effectiveness of government policies.

UN Environment Programme's Principles for Sustainable Insurance Initiative

Endorsed by the UN Secretary-General and insurance industry CEOs, the Principles for Sustainable Insurance (PSI) serve as a global framework for the insurance industry to address environmental, social and governance (ESG) risks and opportunities—and a global initiative to strengthen the insurance industry's contribution as risk managers, insurers and investors to building resilient, inclusive and sustainable communities and economies on a healthy planet.

Developed by UN Environment Programme's Finance Initiative, the PSI was launched at the 2012 UN Conference on Sustainable Development (Rio+20) and has led to the largest collaborative initiative between the UN and the insurance industry. As of October 2022, more than 220 organisations have joined the PSI, including insurers representing about one-third of world premium and USD 15 trillion in assets under management, and the most extensive global network of insurance and stakeholder organisations committed to addressing sustainability challenges. The PSI also hosts the Net-Zero Insurance Alliance and the Sustainable Insurance Facility of the Vulnerable Twenty Group of Finance Ministers (V20).

In 2019, the PSI published, Unwrapping the Risks of Plastic Pollution to the Insurance Industry, the first global insurance industry study on managing the risks associated with plastic pollution, marine plastic litter and microplastics. One of the key findings of the global survey that informed that agenda-setting report is that in the context of plastic pollution risks, liability insurance is the most relevant line of insurance business, followed by marine insurance and health insurance.

This Minderoo report follows that pioneering PSI study. It is intended to serve as an analytical foundation and common reference point to engage the insurance industry on plastic pollution and harness its unique ability to have positive influence on industry and policymakers.

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Cover: Person carries a plastic bag during the lunch hour in Lower Manhattan, January 15, 2019 in New York City. Photo credit: Drew Angerer/Getty Images.

Analytical Partners

Clyde & Co is a leading global law firm, specialising in the sectors that underpin global trade and commercial activity, namely insurance, transport, infrastructure, energy, and trade and commodities. For this report, Clyde & Co contributed Annex 2. Liability Risks arising from the manufacture, distribution, use and disposal of plastics.

Praedicat is the leading liability emerging risk analytics company for casualty insurers and global industrial companies. Praedicat helps companies identify, model, and manage current, emerging, and emergent liability risks, allowing them to adopt new approaches to casualty risks, and to translate them into actionable business opportunities for sustainable, profitable growth. For this report, Praedicat contributed Annex 3.

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Disclaimer

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FOREWORD

Dr Andrew Forrest AO

Chairman, Minderoo Foundation

The conclusions of this report are simple, yet deeply disturbing.

Plastic pollution – in both its visible and more deadly, invisible forms including nano-plastics, the ultimate destination of all plastic and toxic chemical additives – is costing society hundreds of billions of dollars every year, in medical treatment, in environmental clean-up and in great harm to our natural world.

That cost is comparable in size to the revenue of the entire plastics industry, itself.

This report builds on the already compelling evidence that plastic inflicts unacceptable damage on our health – and on that of our children. Arrested cognitive development, reduced reproductive viability, increased cardiovascular disease and obesity. The list goes on – and is increasing in length.

Despite this tragic evidence, corporations continue to release millions of tonnes of plastic products into the environment. They are not being held accountable for the damage they have inflicted, and continue to inflict on humanity, our economy and our communities.

Similar to fossil fuel companies and the climate impact of their products, plastic producers and distributers are the "pin-ups" for having created the most extreme negative nature and human harming externalities ever witnessed in the history of mankind: a price borne by every child, woman and man on this planet.

The industries that are causing this damage are currently acting as free-riders on you, me, all of us and all our offspring. If it included the full cost of the damage, the price of plastics would be a multiple of what it is today – which would open the way for pollution-free alternatives to rapidly overtake this archaic and dangerous industry.

The bill, inevitably, is coming due. Courts, regulators and lawmakers are now paying attention.

For plastics producers, and above all their shareholders and insurers, now is the time to be asking yourself hard questions. What liabilities have your historical emissions left you exposed to? Are you doing enough to eliminate them in the future? What will your personal liability be for only looking at your profit and loss statement?

The question is no longer, are you a good plastics industry director? It is, what are you doing to help society reduce then eliminate burden of ubiquitous and toxic plastic pollution, while you profit from its harm?

Geoff Summerhayes

Former Executive Board Member, Australian Prudential Regulation Authority. Chair of the Project Advisory Board.

The plastic pollution crisis is highly analogous to the climate and biodiversity crises. The catch is, many of us have been unaware of its magnitude and how extensive the damage already is. I was certainly in this category. For much of the last decade, I have been highly engaged on the climate crisis and more recently nature and biodiversity. I consider myself informed – dare I say a leader in the area – and yet plastics harm was not top of mind. That has all changed as this report lays bare. Highly credentialed colleagues on the project Advisory Board have guided this report. They have brought their unique industry perspectives to support Minderoo Foundation's transformative efforts on plastic waste, to quantify social cost and corporate accountability.

Accountability is, however, a conundrum. The potentially catastrophic damage caused by plastic-related pollution stems from a series of events and causes oftentimes so complex as to afford those responsible an effective shield of protection. But the motivation to solve this puzzle is high. The natural, health-related, and economic scale of damage is now starkly clear, and all those affected (governments, cities, investors, and civil society actors) are starting to seek redress.

Currently, only a small subset of damages is expected to translate into financial liabilities to those responsible for them. But as this report outlines, this is changing and likely to do so quickly. Legal theories of causation are evolving, the science of attribution advances quickly, and mass torts are likely to proliferate. Climate-related liabilities can provide a playbook for plastic-related pollution to follow.

Ahead of widespread societal demands for action and accountability, there is a leadership opportunity for corporates, insurers, insurance supervisors and policymakers to work with unprecedented urgency to disclose the magnitude of pollution and damage done to date, to prevent further accumulation of plastic-related toxins, and to set aside the resources required to deal with the consequences. This report is a fact-based resource to guide this effort. Time is of the essence. Collectively we must act for change.

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Large amounts of trash and plastic refuse collect in Ballona Creek after first major rain storm, Culver City, California, USA. Photo credit: Citizen of the Planet/UIG via Getty Images.

HOW TO READ THIS REPORT

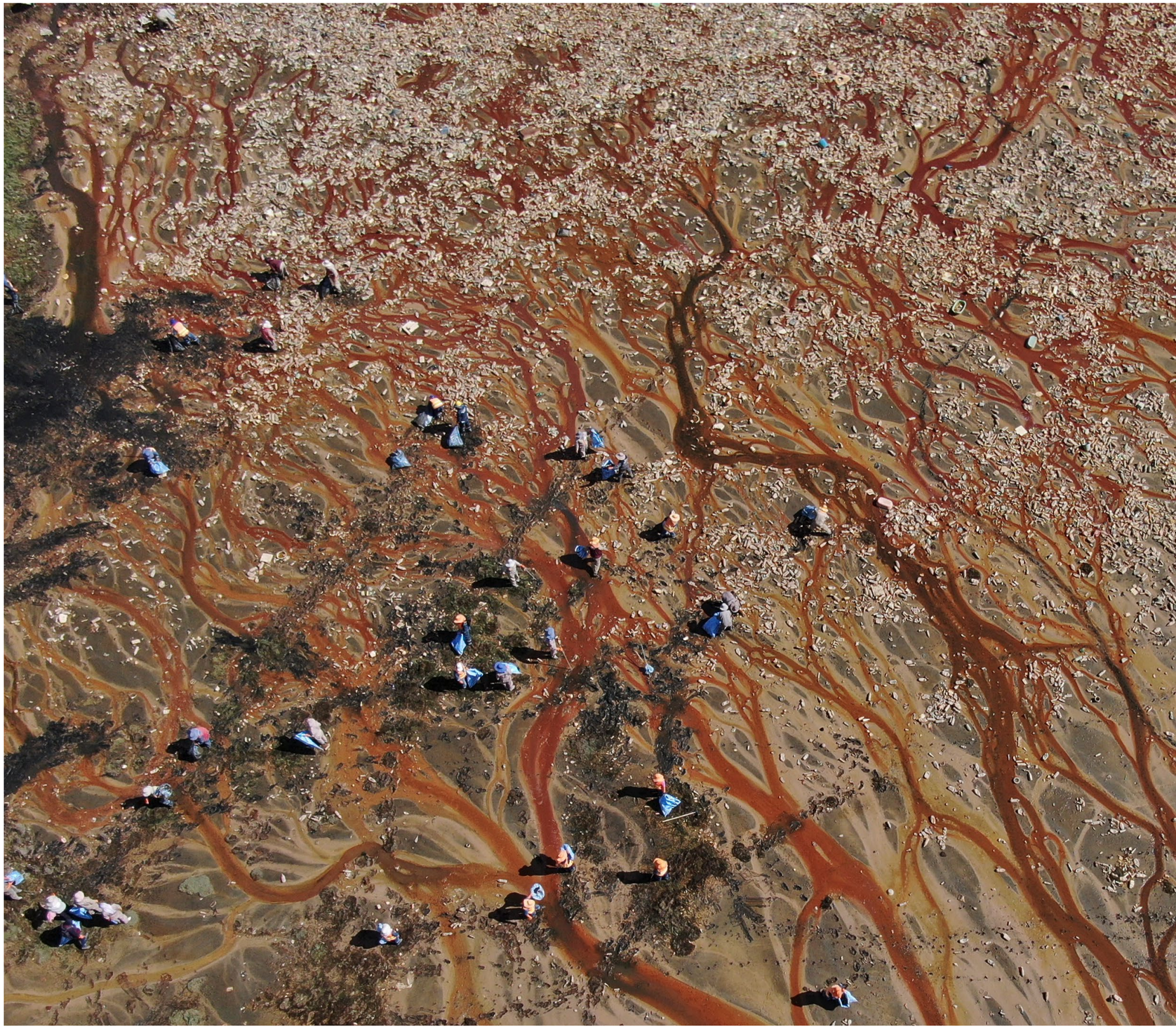
Critical definitions

In this report, “plastic-related pollution” refers to plastic materials (macroplastics, micro/nanoplastics), chemicals/additives, and gases leaked into the environment during the process of primary and secondary plastic production, consumer use, and post-consumer use. It also includes the chemicals that can adsorb onto plastic materials after they leak into the environment.

“Plastic industry” refers to producers of primary plastic polymers and associated additives (petro/chemicals); designers and producers of plastic goods in various sectors (packaging, transportation, medical equipment, construction); consumer brands using plastic packaging, and their retailers; waste managers; and plastic recyclers.

Report Structure

The Price of Plastic Pollution	Target Reader
Executive Summary A synthesis of the key findings from our research and implications for all stakeholders concerned.	Any reader with an interest in understanding and solving the problem of plastic pollutions.
Main Report (chapters 1–5) Framing the scope, describing the methodologies used, and exploring the results in more detail.	Plastics and finance industry professionals; policymakers and civil society representatives working on plastics and chemical pollution.
Technical Annexes Detailed methodologies, comprehensive results, technical discussion and full external references. 1. *‘The Social Cost of Plastic-Related Harms’* 2. *‘Liability risks arising from the manufacture, distribution, use and disposal of plastics’* 3. *‘Quantifying Plastic Risk to Corporates and their insurers’*	Technical experts in the fields of academia (health, environment, economics), law (tort), and insurance (liability).



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An aerial view of as volunteers and employees of the municipality and state companies work cleaning contaminated area with garbage, plastic recipients, bottles and toxic waste generated by mining companies which have polluted the Tagarete River which flows into Uru Uru Lake on April 08, 2021, near Oruro, Bolivia. Photo credit: Gaston Brito Miserocchi/Getty Images

EXECUTIVE SUMMARY

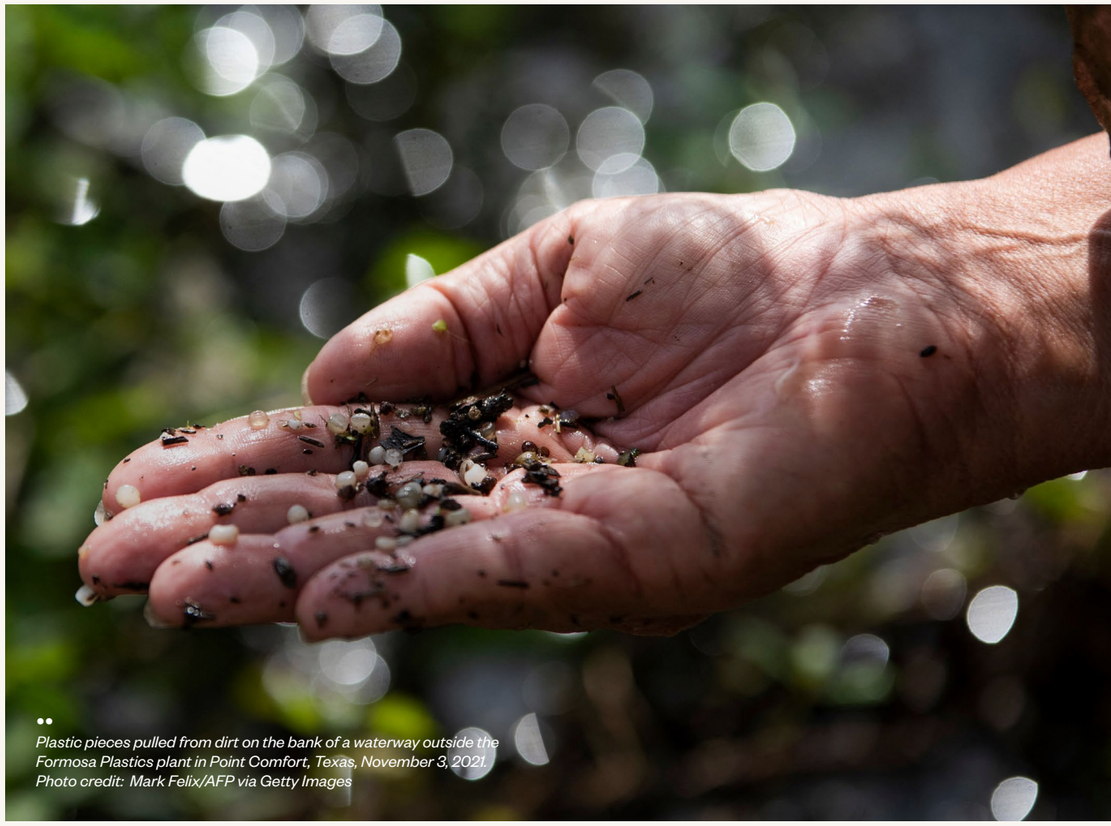
Plastic-related pollution is long-lived, cumulative, mobile, and now ubiquitous. It harms people, nature and the economy ("social costs"). Some social costs will inevitably turn into compensation claims against the plastics industry ("corporate liabilities"), which in turn may present these claims to their insurers. In this report, for the first time, we attempt to provide quantitative estimates of both the social costs and the corporate liabilities emerging from all forms of plastic-related pollution.

In doing so, our objective is two-fold:

1. By describing the corporate liabilities facing the plastics industry, its insurers and investors, and their supervisors, we guide where to prioritise actions to reduce business risks arising from plastic-related pollution.
2. By highlighting the discrepancy between social costs and corporate liabilities, we initiate wider discussions on the progress legal systems are making in deterring harm and/or providing means of redress; on the plastics industry's continued social licence to operate; and on the actions required by policymakers to close the accountability gap and counter plastic-related pollution.

We estimate the social costs arising from all forms of plastic-related pollution – although dependent on imperfect assumptions – to be hundreds of billions of dollars each year, much of it driven by harms to human health. For context, in 2021, the global plastics market was worth approximately US$600 billion.

Corporate liabilities are emerging from a subset of these harms. In the near term, we expect claims relating to human exposures to chemical additives to predominate in terms of activity and severity. We expect claims to emerge from environmental damage, and also potentially relating to human exposures to micro and nanoplastics ("MNP"). In addition, further legal action is already building against plastics companies and their directors for misleading behaviours related to their sustainability claims ("greenwashing").



Plastic pieces pulled from dirt on the bank of a waterway outside the Formosa Plastics plant in Point Comfort, Texas, November 3, 2021. Photo credit: Mark Felix/AFP via Getty Images

Our estimate of the expected corporate liabilities from plastics litigation triggered in the period 2022-30 ("expected liabilities") is preliminary but exceeds US$20 billion in the United States alone, which will be the centre of claims activity and where probable maximum liabilities (1% probability) could exceed US$100 billion. Risks are concentrated on specific sub-sectors of the plastic supply chain – principally on manufacturers of specific chemicals and primary polymers – magnifying their potential impact and the need for corrective action.

The discrepancy between massive social costs and the material, but far lower, corporate liabilities is both remarkable and inequitable. It is driven, in part, by the immaturity of plastics litigation activity, and also by prevailing legal standards on the burden of proof – what caused the harm, who caused it, how much was known in advance ("causation"). Here, plastic-related pollution has unique complexity due to the number of actors in the supply chain, multiple sources and points of exposure, its ubiquity, and the fact that other environmental factors can be linked to similar harms. Climate-related liabilities are facing similar challenges in attributing the damage done to specific actors.

However, systems of justice will catch up as rapid advances are made in the science of attributing specific causes to complex outcomes, and as lawyers successfully develop new and alternative theories of causation. There is a real possibility of a major increase in claims activity and severity in the medium term. The exposures occurring now and in the near future could significantly affect the plastics industry, and their insurers, and therefore require the immediate attention of both.

But we cannot rely exclusively on legal channels to compensate society for the harms caused by the plastics industry. There are damaging – and, in the long-term, potentially catastrophic – harms from plastic-related pollution, including those affecting our ocean, that as yet have no legal pathway for redress. New, previously unknown harms will also emerge. This poses challenging questions for the plastics industry, insurers, and society at large, about how the risks and costs of these harms are prevented, mitigated and distributed – and must form part of the ongoing negotiations for a legally-binding global treaty on plastic pollution.

Key finding 1

Near-term exposures (2022-30) to corporate liabilities from plastic-related pollution are material and likely to exceed US$20 billion.

There is robust scientific consensus on plastic-related pollution causing societal harms.[1] While the level of expected claims activity and severity may be limited by prevailing legal doctrines on causation[2], corporate liabilities are likely to emerge across five pathways (prioritised here by potential magnitude of social cost, scientific consensus on causation, likely claims activity and likely claims severity; and summarised in Table 1):

1. **Plastic-related chemicals and bodily injury.**

   There is robust scientific consensus on human health harms resulting from some of the performance-enhancing chemical additives used in plastics, namely certain phthalates, bisphenols and flame retardants.[3] All three classes contain known endocrine disruptors and are linked to significant health problems: infertility, early puberty, developmental issues such as ADHD and autism, and metabolic disorders such as type II diabetes and obesity. We estimate that the global social costs associated with these plastic-related chemicals exceed US$100 billion per annum.[4] Many relevant precedents exist in the field of employers' liability litigation, and US public nuisance law could also provide a viable basis for claims (analogous to recent opioids litigation)[5]. In the US, expected liabilities are estimated to be US$20 billion, with probable maximum liabilities (1% probability) for phthalates reaching US$100 billion.[6] Manufacturers of the chemicals of concern are likely to be most exposed to risk[7]. Insurance claims will typically fall under employer's liability and general liability coverage[8].

2. **Micro and nanoplastics (MNP) and bodily injury.**

   There is emerging evidence on human health harms (mostly inferred from animal studies) resulting from MNP ingestion.[9] Our current estimate of the social cost is limited to gastrointestinal tract disorders (where there is now human epidemiological evidence), but still exceeds US$10 billion per annum given the global ubiquity of exposure.[10]

   Tracing harms to specific exposures or defendants, and ruling out other causes of injury, may remain challenging in the near future, and claimants may also require proof that manufacturers had knowledge of their products' dangerous properties. However, public nuisance law could, again, provide a viable basis for claims and it is possible that there is such litigation starting before 2030. Expected liabilities are estimated to be just above US$100 million (US only), with maximum probable liabilities (1% probability) of US$3 billion.[11] As with chemical exposures, it is likely that the original producers of the litigated hazard (i.e., primary plastics manufacturers) take much of the responsibility[12]. Insurance claims will typically fall under general liability coverage.

3. **MNP and property damage.**

   There is emerging evidence of harms to human from MNP in waste and drinking water. This could result in liability claims for property damage and remediation costs for the upgrade of water treatment facilities (subject to the same hurdles described above for bodily injury), especially as regulators increasingly consider MNP contamination in their risk-based water quality standards. The costs of these upgrades could well exceed US$100 billion in the US alone.[13] We expect that public and private water utilities will seek to recover these costs from the plastics industry to the degree it is able to pay.[14] Claims will typically fall under general liability coverage. As these policies are likely to be written on an "occurrence" basis, current and cumulative MNP exposures may be material to property damage claims many years from now (e.g., when water quality regulations force the issue).*

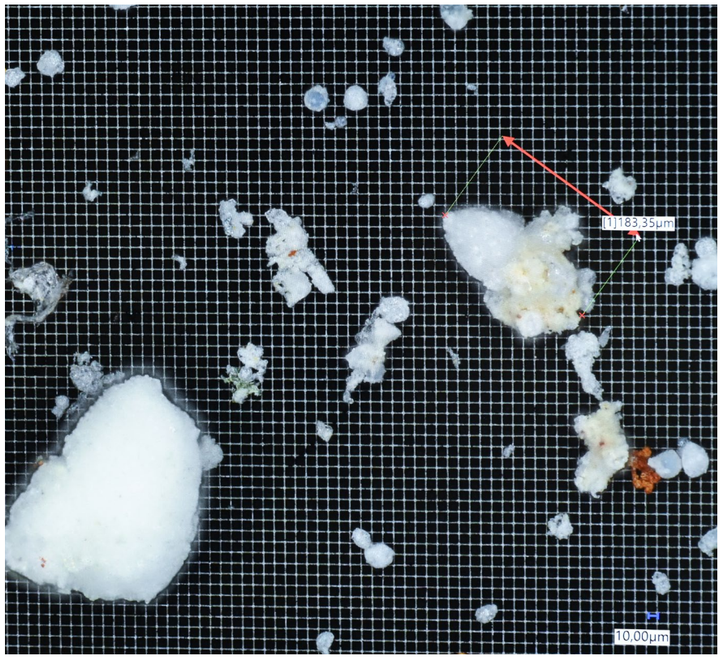
* *This also holds true for bodily injury from chemical additives and MNP*

4. **Environmental damage.**

   Regulators have extensive powers to seek redress for environmental clean-up costs, relevant for damage caused by chemicals, macroplastic and/or MNP (similar to recent PFAS litigation). Expected costs are yet to be modelled but remediation in analogous contexts has proven to be both technically difficult and expensive, albeit confined to specific locations. These risks will typically fall under environmental liability coverage areas. These policies are likely written on a "claims made" basis, which may limit any liabilities related to past and cumulative exposures.

5. **Misleading behaviour.**

   While not strictly a "social cost", there is a growing body of precedent for breach of consumer protection laws and/or loss of shareholder value from greenwashing claims, in the form of consumer class action complaints and investor lawsuits. In all jurisdictions under consideration, regulators have extensive rights to require the withdrawal of misleading consumer statements, and significant fines and sanctions may be imposed for breach, albeit on a smaller scale than for bodily injury. Shareholder losses can also be extensive. Insurance claims will typically fall under general liability or director and officer coverage areas.



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Plastic particles viewed through a 3D microscope at the Institute of Environmental and Process Engineering at RhineMain University of Applied Sciences. The specific dangers posed by microplastics or the even smaller nanoplastics - are currently still the subject of research. It is already clear that particularly small particles can penetrate cells and trigger reactions there. These nanoparticles are found in cosmetics, for example. Photo credit: Arne Dedert/picture alliance via Getty Images

Table 1: Summary of five pathways to corporate liability from plastic-related pollution

		1. Plastic-related chemicals and bodily injury	2. MNP and bodily injury	3. MNP and property damage	4. Environmental damage	5. Misleading behaviour
Expected social cost of plastic-related harms	**Scientific consensus that hazard causes harm through plastics-related exposure**[15]	High	Medium	Medium	High	N/A
	Estimate of size of social cost[16]	> US$100 B per annum	US$10 to 100 B per annum	> US$100 B per annum	US$10 to 100 B per annum	N/A
	Likelihood that consensus (and size) remain static[17]	High	Low	Low	Medium/High	N/A
Potential claims pathway(s)	**Liability pathway**[18]	Exposure causing injury to employees, consumers or to the public	Exposure causing injury to consumers or to the public	Exposure causing damage to public infrastructure	Escape of harmful substances from plastics manufacture, use or degradation	Greenwashing as a breach of consumer protection law or loss of shareholder value
	Type of insurance coverage[19]	Employers' liability or general liability (product and public liability sections)	General liability (product and public liability sections)	General liability (property damage and public liability sections)	Environmental liability	General liability (advertising injury section)[20] or director & officer
Estimated current exposure to corporate liabilities	**Expected liabilities (from litigation triggered in 2022-30; US only)**	US$22 B[21]	US$100 M[22]	Not estimated	Not estimated	US$250 M to 1 B[23]
	Probable maximum liabilities (1% probability; US only)	US$100 B[24]	US$3 B[25]	Not estimated	Not estimated	Not estimated
	Likely primary exposed party	Plastic-related chemical manufacturers[26]	Polymer manufacturers[27]	Polymer manufacturers[28]	Polymer and plastic-related chemical manufacturers	All companies in the plastics industry

Key finding 2

Future exposures (beyond 2030) to corporate liabilities may increase by an order of magnitude and demand immediate attention.

We expect meaningful advances in scientific methods and in the evolution of legal doctrines and standards. Together, these will lead to a marked increase in future liability claims – which may well dwarf the near-term corporate liabilities.

Influential advances in science and legal doctrine include[29] :

- Progress in the attribution of plastic-related pollution to specific harms (especially in linking MNP pollution to bodily injury).
- Ongoing advancement in toxicology (methods, number of chemicals investigated, MNPs as potential chemical transmission pathways).
- Recognition of latent long-term cumulative exposure effects, such as those experienced by factory workers and pollution-exposed communities.
- Legal standards expanding from conventional causational theory, and increasingly accommodating theories of complex and shared causation of harm[30].
- Greater adoption of mass litigation action outside the US, supported by growth in sponsors of litigation and greater availability of collective redress procedures[31].
- Evolving regulations on plastic-related pollution, such as a legally-binding global treaty on plastic-related pollution currently under negotiation[32].

Many exposed industries that may be found liable for their manufacture, use, or disposal of plastics have not faced litigation for these activities in the past and so it is unlikely that their insurance has priced these risks into the coverage. The higher cost outcomes of future plastic-related litigation could present a potential solvency issue for insurers if preventative action is not taken.

Key finding 3

There will remain a gulf in size between social costs and corporate liabilities, demanding a re-evaluation of how risks are mitigated and costs are shared.

While the near-term exposures to corporate liabilities are material and future exposures could be an order of magnitude larger, the diversity and ubiquity of plastic-related pollution mean that its social cost – which already runs into hundreds of billions of dollars each year – will not be fully compensated through the courts. Two factors are at play, one specific to plastics, the other applicable to any latent harm:

- Certain significant social costs are unlikely to have any legal pathway to redress in the near-to-medium term. These include harms to marine natural capital (e.g., harms to ocean ecosystems) from all forms of plastic-related pollution, and "indirect" harms to human health and the economy from plastics acting as aggregators of toxins (e.g., the adsorption of heavy metals and/or pharmaceuticals by MNP).[33, 34] There is a "double lag" between corporate actions and legal consequences: first, the lagtime between exposure to a hazard and the harm, which in many cases will only appear years later; and second, the lagtime between awareness of a potential hazard/harm link, and the required scientific and legal enquiry into causation. As a result, corporate liability risk is often so far into the future that companies, directors, and shareholders are not compelled to be sufficiently precautionary in introducing novel entities into the stream of commerce.

Implications & priorities for managing risk

Immediate action is required from corporates, their insurers, their shareholders and investors, insurance supervisors, and policymakers to address near-term and future liability risks from plastic-related pollution.

A. **Corporates** must clearly disclose where their business has exposure pathways to plastic-related pollution. Their approach to science, regulation, public communication, and product design should be driven by a sincere and precautionary focus on harm reduction.

B. **Insurers** play an essential role in harm reduction. Once they have a full view of potential exposure in their policy portfolio, they are in strong position to: i) proactively engage plastics industry clients on mitigating exposure and managing transition risk; ii) create incentives to drive the desired and required changes in behaviour; iii) provide a rigorous quantitative foundation on emerging risks and scenarios to policymakers; and iv) support stricter standards covering toxicity and circular material management practices. Insurers can extend their leadership on this issue by engaging policymakers to support the development of a strong legally-binding global plastics treaty that mitigates a range of risk scenarios.

C. **Investors** should demand disclosure of their portfolio companies' plastic-related pollution risks and exposures, promote their commitments to specific targets, and align these targets with their investment strategies. As good corporate citizens, their support of investment practices designed to reduce harm should go beyond the confines of their current portfolios.

D. **Insurance supervisors** should develop an independent view on the potential exposure to liabilities at the individual and insurance industry level (micro and macroprudential), and model the risk of disruption to the financial sector from potential large scale losses resulting from plastic-related pollution. This is highly analogous to prudential regulatory responses to climate risk. Once the scale of potential exposure is fully understood, supervisors can ensure capitalisation requirements for plastic-related pollution liabilities are being met. Supervisors should track relevant developments in attribution science and in legal theories of causation.

E. **Policymakers** have an unprecedented opportunity to address the risks and social costs associated with the lifecycle of plastics under the international legally-binding instrument to end plastic pollution, currently being negotiated. Policymakers should draw on scientific research on human health and environmental harms, as well as economic insights into the social costs of these harms, to ensure that the international instrument is an ambitious and effective global response to the problem of plastic-related pollution. In both national and international regulatory regimes, a more precautionary approach to the release of novel entities into the stream of commerce is essential, especially in regards to human health impacts.

INTRODUCTION

This report describes the state of plastic-related pollution and emerging liability risk, and the implications thereof for corporates, their insurers and other stakeholders.

The focus is on the harms and costs of plastic-related pollution to society. The report does not consider the benefits of plastics or estimate their net value, based on the assumption that the harms of plastic-related pollution can be solved or mitigated without eradicating plastics altogether. Our approach is intended to be iterative, providing a structure for analysis, quantification and prioritisation of plastic-related pollution risks, and consists of three steps:

A. Estimate social costs.

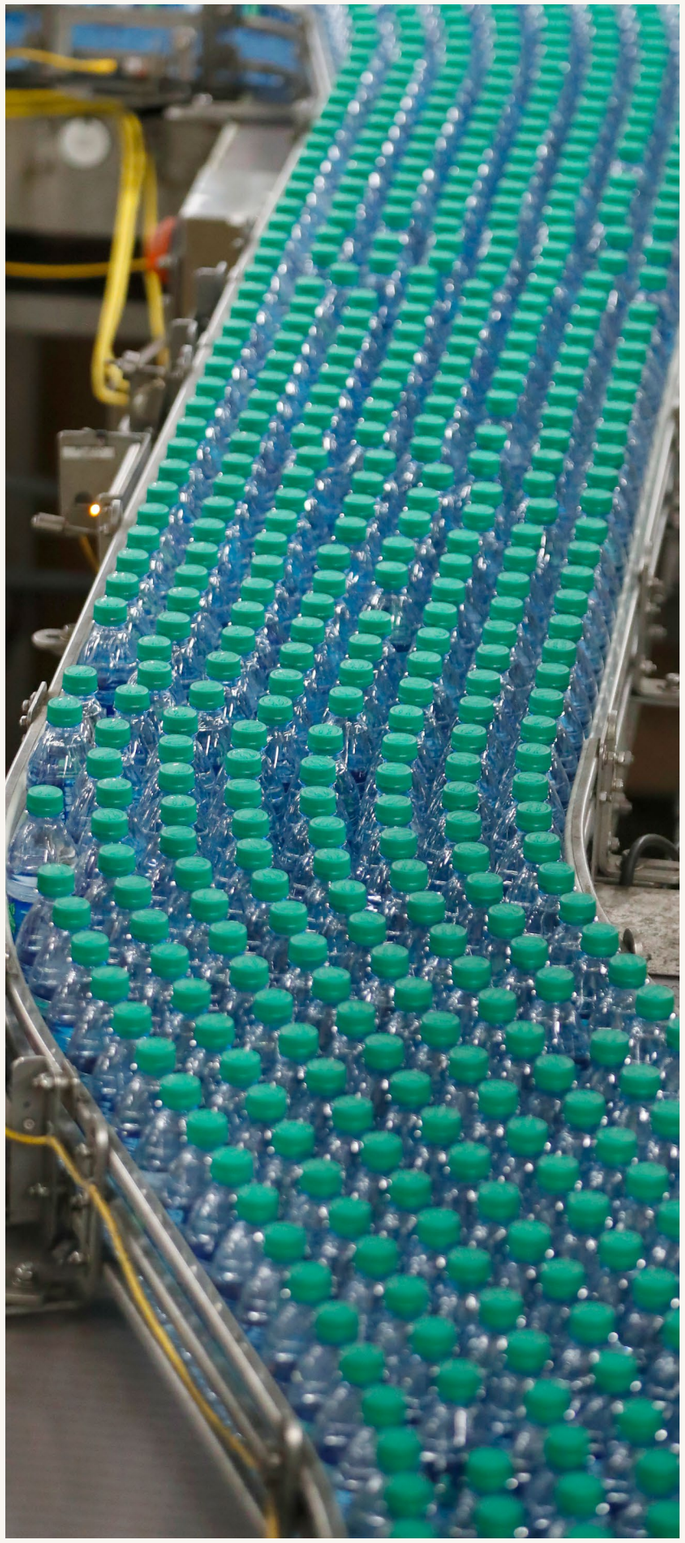
We begin with the potential harms that plastic-related pollution can cause to society (people, nature, economies), considering the certainty, magnitude and potential costs of all plastic-related pollution hazards and harms examined in the scientific literature. We categorise and prioritise these harms based on their potential relevance to corporate liabilities now and in the near future.[35]

B. Assess legal pathways to litigation.

We then explore the legal doctrines, standards and precedents applying to the most significant liabilities to corporates. This yields a further prioritisation of harms in terms of their potential for causing claims activity and the likely severity of those claims.

C. Quantify potential claims activity.

Finally, we combine social costs and legal pathways, and estimate the potential financial exposures facing the plastic industry from liability claims (defence costs and damages for litigation triggered in the period 2022-30). Implications for all stakeholders – corporates, re/insurers, investors, policymakers, and supervisors – are explored via a shortlist of recommended actions, as well as remaining knowledge gaps. We do not assess insurance coverage implications.



Fundamentally, the hazards, harms and risks associated with plastic-related pollution are shaped by the prevalence, chemical composition, and mobility of plastic in the environment.[36] These factors drive three basic insights around which this report is structured:

A. Evidence of societal exposure and harm is robust.

The current and emerging science is robust and unequivocally stated in over 5,000 papers: plastic-related pollution harms humans, nature, and the economy.[37] While many harms are well understood in terms of causation and magnitude of harm, others remain in emerging, indeterminate, or immature categories, requiring further study.[38] The growth in studies on plastic-related harms over the past five years has been exponential.[39]

B. Litigation risk exists and has potential to expand rapidly.

Scientifically proven plastic-related harms may trigger litigation where they can be shown to cause bodily injury, property damage, environmental damage, and/or involve misleading behaviour. Litigation pathways, while already manifesting for some harms, are for others limited by uncertainties relating to exposure, causation, attribution, and culpability; however, many uncertainties will disappear as advances occur in scientific understanding (particularly attribution) and legal doctrines (particularly theories of shared causation).

C. Near-term exposures to corporate liabilities are material; in future scenarios they could be massive.

In the near term, plastic-related liabilities are most likely to arise from harms to human health from certain classes of chemical additives, from claims relating to environmental damage, and from greenwashing. Harms to human health and property, may result in tentative litigation efforts in the same timeframe, but are more likely to be the portent of a far greater future wave of claims activity – one more commensurate with the ubiquity of plastic pollution.

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Bottled water moves down a production line at a Coca-Cola bottling plant on February 10, 2017 in Salt Lake City, Utah. Photo credit: George Frey/ Getty Images.

THE SOCIAL COST OF PLASTIC-RELATED HARMS

For a fully referenced technical description of methodology and results, see Annex 1[40]

Physical fundamentals of plastics

Plastics are polymers – engineered chains of repeated small hydrocarbon building blocks. Into this polymer matrix, over 10,000 registered additives and processing agents are incorporated as plasticisers, flame retardants, antioxidants, UV stabilisers and pigments, including bisphenols (in polycarbonates, epoxy resins); plasticisers (phthalates and N-butylbenylsulfonamide); and flame retardants (brominated and phosphate-based). Many of these additives and processing agents are not yet toxicologically evaluated, while 1,254 have been identified as substances of high concern.[41] Some of them, such as perfluorinated chemicals, bisphenols and phthalate plasticisers, and certain flame retardants, are routinely used, known to be toxic to humans, and leach into the environment. Plastics are cheap, long-lived, light, and strong – precisely the same qualities that make them challenging to manage post consumer use.

Plastic-related pollution enters the environment during all phases of the plastic life cycle, from production to consumer and industrial use, waste management, and post-consumer "leakage".[42] It occurs in a variety of sizes, from the nano- to macro scales. Mismanaged plastic waste is projected to grow from 90 million metric tons (MMT) per annum to 240 MMTs per annum in 2040, with an estimated 6–8 billion MMTs of plastic pollution already accumulated in the environment,[43] where it is ubiquitous in oceans, fresh water and air, and thus widely found inside animals, plants, and humans.

Plastics are persistent, with half-lives measured in centuries and negligible chemical breakdown. This makes plastic exposure in organisms and tissue cumulative, with potentially important implications for toxicity. Organic pollutants such as brominated flame retardants, dioxins, and furans that were, and in many cases still are, commonly used as plastic additives are also highly persistent and prone to bioaccumulation.[44,45] Plastic-related pollutants are highly mobile, travelling easily and widely in the environment. Within organisms, nanoplastics are bioavailable because, like other nanomaterials, they can cross tissue and cellular membranes, may be able to bioaccumulate, and might undergo trophic magnification up the food web.[46]

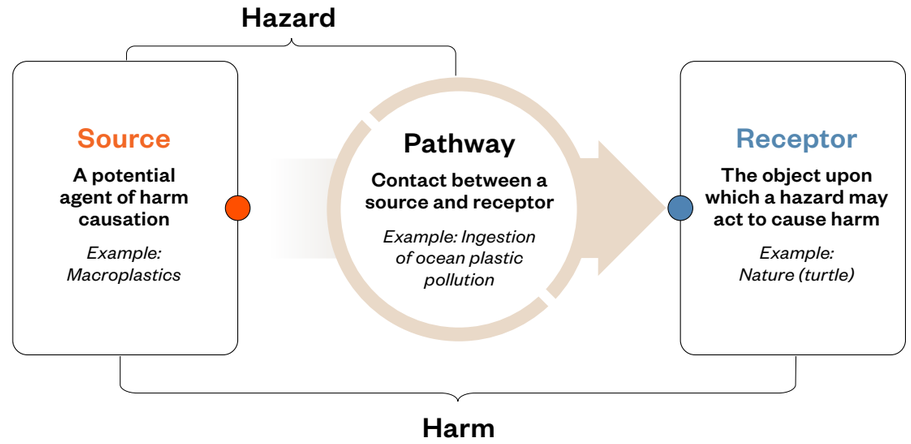
Scope of analysis

Current and emerging science provides robust evidence that exposure to plastic (macroplastic, MNP, associated chemicals and carbon emissions) harms human health, nature, and economies and ecosystem services (see **Figures 1 & 2** for definitions for key terms).

Figure 1: Framework for harm identification

	Receptors		
Sources	**Human Health** Disease, injury, or other adverse health outcomes in humans	**Economies & Ecosystem Services** Losses in income, asset value, or natural capital	**Nature** Disease, injury, and other adverse health outcomes in plants & non-human animals
Chemical additives	The effects of the different types of chemicals added to plastics to give them specific properties or otherwise make them more useful for their intended purpose		
Macroplastics	The effects caused by plastic products >5mm in diameter, and the direct effects of their lifecycle from production to end-of-life disposal		
MNPs	The effects of pieces of plastic that are <5mm in diameter created for a specific use (primary MNPs) or fragmented from larger pieces of plastic (secondary MNPs)		
CO_2e emissions and climate change	The effects of the emissions from CO_2 and other greenhouse gases (GHG), which are released at a number of points in the plastic lifecycle		

Figure 2: Definition of key concepts



Scientific attention and coverage*

Journal publications on plastic-related risks are proliferating. For example, MNP-related papers grew from 2,500 in 2021 to an estimated 4,500 in 2022.[47] Well-diversified in terms of authors**, subjects, journals, and countries of origin, the MNP literature covers environmental studies (35%), laboratory studies (18%), technique development (10%), physical and chemical properties (9%), as well as human exposure (5%; **Figure 3**). In addition, more than 5,000 papers describe the plastic-related harms to human health. These papers are almost equally divided into coverage of the major plastics-related chemicals: phthalates, flame retardants, and bisphenols.[48]

* *Analysis of scientific coverage and research trends was performed by Praedicat.*

** *No single author is listed on more than 54 papers, amounting to 1.26% of the literature.*

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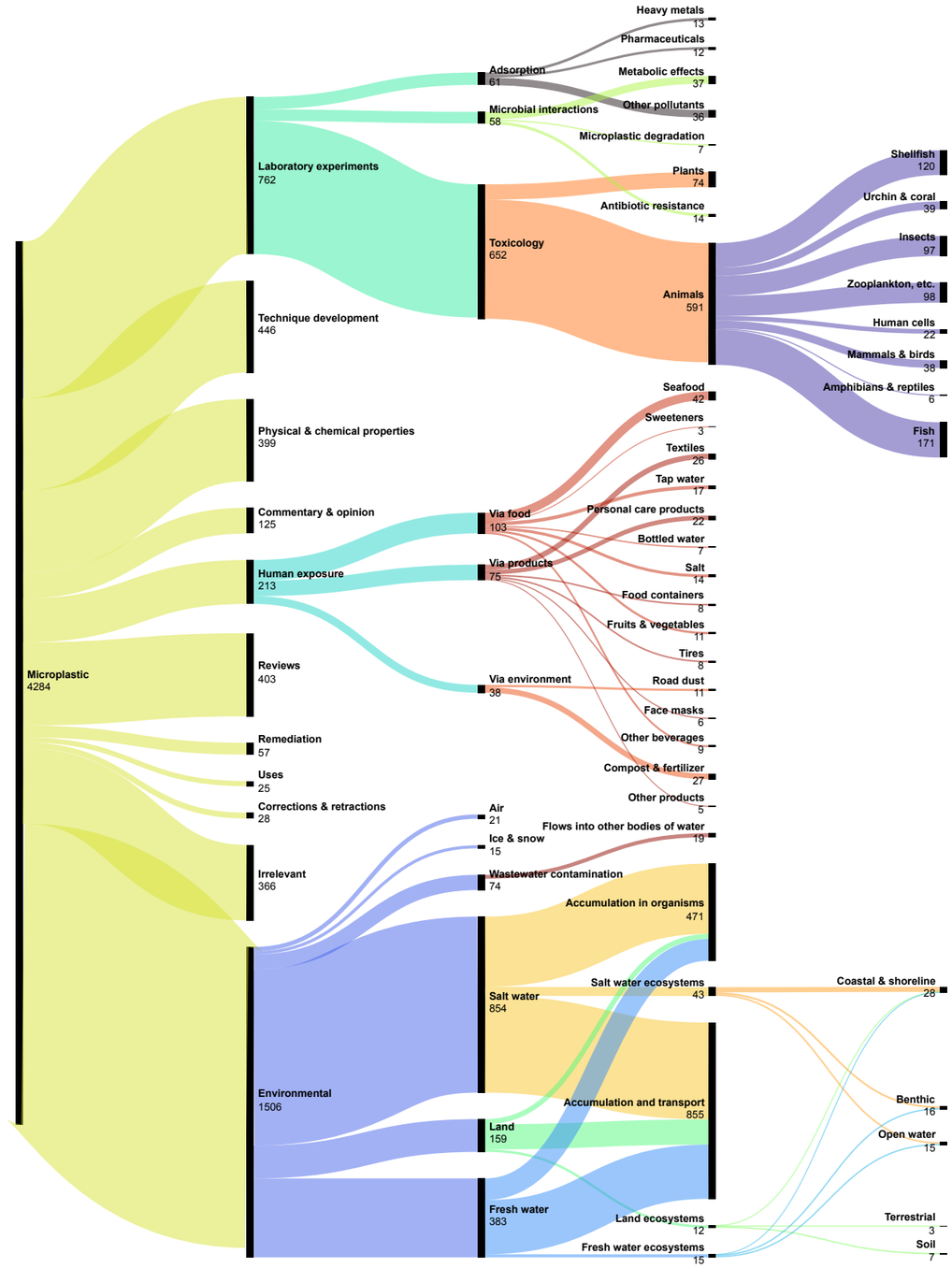
Close up side shot of microplastics on a persons hand.
Photo credit: Getty Images.

Figure 3: Distribution of MNP research, courtesy of Praedicat



Research methods include:[49]

A. Laboratory studies focused on toxicology, chemical adsorption, and impacts on microbes and animal models. There have been no toxicology laboratory studies conducted in humans, for obvious ethical reasons.
B. Human exposure studies. These examine the pathways and magnitude of exposure (environmental, from food, or from other commercial products).
C. Epidemiology studies. These examine the outcomes of humans exposed to a hazard compared to those with lower exposure. The studies may be conducted prospectively or retrospectively and with various designs.
D. Environmental studies, covering the presence of plastic-related pollution in specific locations, their effects on exposed flora and fauna, and prevalent transportation mechanisms. Locations studied include wastewater, air, ice and snow, salt water, fresh water, and land.
E. Meta-analyses and scientific reviews which synthesise the scientific consensus on specific hazards, pathways, receptors and harms.

While the science is increasingly converging, analytical uncertainties remain, especially concerning the attribution of plastic-related exposures to harms ("causation"). These include harms caused by multiple and compounding chemicals, the absence and difficulty of controlled studies on human exposure, and the lack of detailed toxicologies for many of the chemicals routinely used in plastic.[50]

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One of the world's first plastics contamination-controlled laboratories - a partnership between the University of Queensland and Minderoo Foundation - will enable ground-breaking research using state-of-the-art equipment and specific techniques to measure nanoplastics in samples. Photo credit: Minderoo Foundation

Expected social cost of plastic-related harms

Assessment methodology

Our methodology for assessing the social costs of plastic-related pollution follows three steps:

Step 1:
Develop a comprehensive list of specific harms.

A long-list of individual harms was prepared by reviewing the academic literature on sources (macroplastic, MNP, chemical additives, and greenhouse gas emissions) and receptors (human health, economy and ecosystem services, and nature). A summary table consolidating individual harms into groups has been developed (see **Figure 4**).[51]

Figure 4: Taxonomy

	Vector	Receptor	Consolidated harm
1	Chemical Additives	Human health	Human harm from bisphenols
2			Human harm from flame retardants
3			Human harm from PFAS
4			Human harm from phthalates
5			Human harm from unidentified or other chemicals
6		Economies & ecosystem services	Harm to food sources (aquatic and terrestrial) from chemical additives
7		Nature	Harm to organisms from chemical additives
8	Macroplastics	Human health	Human harm from informal end-of-life burning of macroplastics
9			Human harm from air pollution from macroplastic production
10		Economies & ecosystem services	Harm to food sources (aquatic and terrestrial) from macroplastics
11			Harm to tourism from macroplastics
12		Nature	Harm to organisms from macroplastics
13	Micro & nano-plastics	Human health	Human harm from MNPs (direct: from plastic materials)
14			Human harm from MNPs (indirect: via adsorption of contaminants)
15		Economies & ecosystem services	Harm to food sources (aquatic and terrestrial) from MNPs (direct: from plastic materials)
16			Harm to food sources from MNPs (Indirect: via adsorption of contaminants)
17			Harm to water sanitation from MNPs
18		Nature	Harm to organisms from MNPs (direct and indirect)
19	CO_2e emissions	All	Carbon emissions and climate change
20	All Plastics	Economies & ecosystem services	Harm to marine natural capital

Step 2:
Estimate the expected social cost of each harm.

The science on plastic-related pollution is highly dynamic, requiring a rigorous meta-analytical approach to assessing each harm's size and its probability of occurrence, and the degree to which our understanding of these two might change over time (see **Figure 5**)[52]

A. Size.

The magnitude of any hazard's harm was measured by the "excess burden" it creates and the costs thereby incurred. Taking a human health example, the "excess burden" of a plastic-related pollution-caused disease was measured in terms of disability-adjusted life years (DALYs) lost to ill health or early death; the "cost" of each DALY was set as the global average of "willingness to pay" surveys. The "size" of the harm is a multiplication of the two. As an additional complication, plastic-related pollution contributes to the total harm done by some chemicals much more than others (e.g., PFAS is more widely used in non-plastic applications). This plastic "contribution" was therefore also incorporated.[53]

B. Probability.

The probability of a hazard causing harm was determined by current scientific consensus. "Current consensus" on human health harms was determined by a systematic and carefully scored assessment of over 5,000 studies using criteria of quality, relevance, and concentration (i.e., number of studies supporting the same finding).[54] The same criteria were used to assess non-human health harms, although the analysis relied more upon expert interviews and review of the most relevant literature.

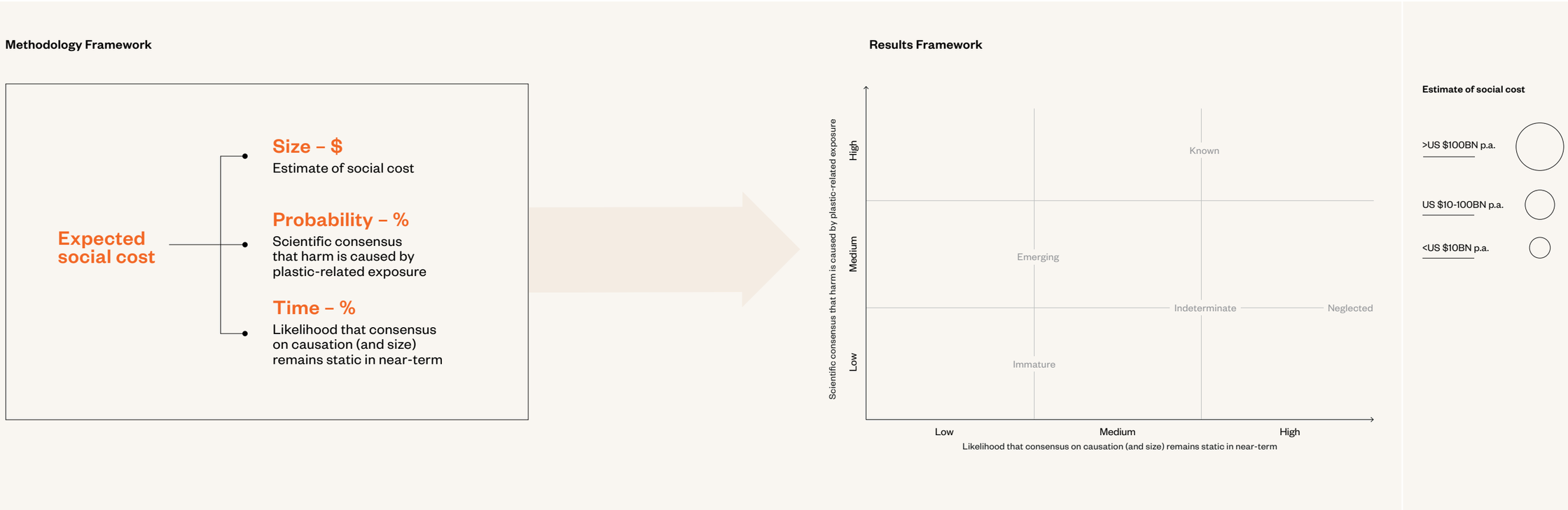
C. Time.

Estimates of size and probability are based on today's scientific knowledge. But the science can also be an indicator of how understanding of emerging harms may evolve over time, defined as the "likelihood that consensus on causation (and size) remains static". This dimension was assessed using criteria of growth (three-year change in numbers of published studies for human health harms) and timeframe (years since published studies began).

Step 3:
Group the harms into "clusters".

By plotting these assessments of harm based on size, probability and time we were able to develop "clusters" of social costs that are indicative of relevance to potential corporate liability risk. Several categories of harms emerged. Occupying opposite ends of the spectrum, "known" harms accord with a mature scientific consensus, while "immature" harms lack consensus and are thus likely to change. In the middle, a group of "emerging" harms feature rapidly converging science and looming consensus which could lead to rapid initiation of action. Finally, there is a group of "indeterminate" harms. These are characterised by an incomplete understanding of causation which, given the lack of research activity, is unlikely to change in the near and medium term.[55]

Figure 5: Integration of Steps 1–3 in the methodology for assessing the social costs of plastic-related pollution



Results

A systematic ranking of the size, probability and time dimensions of harms yields four clusters with distinctly different outlooks for corporate liabilities (**Figure 6**). These clusters provide the basis for analysing the many harms and risks associated with plastic-related pollution.[56]

Known harms

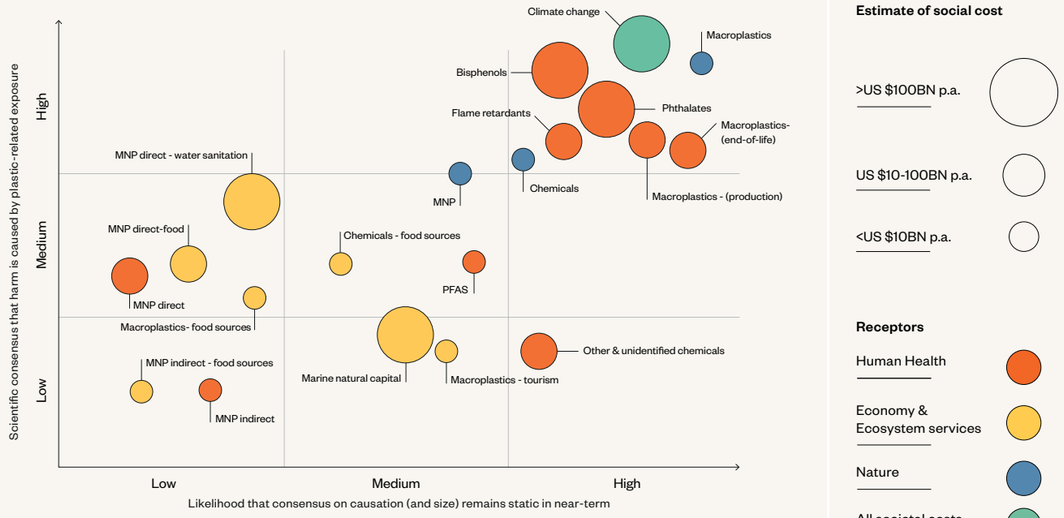
This cluster, defined by a mature scientific consensus on causation, includes:

A. Harms to human health. Sources include chemicals/additives (phthalates, fire retardants, and bisphenols) and the informal burning of plastic waste in emerging economies. The social cost of harm to human health from phthalates and bisphenols is estimated to exceed US$100 billion per annum. Regulation of these chemicals is evolving, heterogeneous, and rarely precautionary.[57]

B. Harms to nature. Nature's intrinsic or "heritage" value to society is harmed by macroplastics, chemical additives and MNPs. Nature's intrinsic value is inherently difficult to value, with methods ranging from "willingness to pay" to "remedial costs". Willingness to pay estimates are low (less than US$10 billion per annum), while remediation costs are potentially so high as to be economically infeasible. Acknowledging that neither method provides for a satisfactory estimate, we have chosen the willingness to pay estimate (also recognising that harms to nature's ecosystem services were addressed separately in this analysis – see discussion on "indeterminate harms").[58]

C. Climate-related harms from plastics-mediated greenhouse gas emissions. Total climate-related social costs due to plastic-related pollution are likely to exceed US$100 billion per annum.[59]

Figure 6: Results of assessment of expected social cost of plastic-related harms



Emerging harms:

This cluster, defined by emerging scientific consensus on causation, is dominated by MNP. Their direct effects on human health include inflammatory responses, intracellular responses (nanoplastics), or potentially mechanical damage (microplastics). Calculation of social costs is based on gastro-intestinal health harms – where the only epidemiological research on MNP exists – and estimated between US$10 and $100 billion per annum. Potential MNP-related water remediation costs are also expected to significantly exceed US$100 billion per annum.[60]

Immature harms:

This cluster, defined by immature, likely-to-change scientific consensus on causation, features harms indirectly caused by MNP acting as vectors for other contaminants (e.g., heavy metals, pharmaceuticals). There is considerable research underway on their effect on human health and on food sources and production, with expected potential social costs on each of less than US$10 billion per annum.

Indeterminate harms:

This cluster, defined by incomplete scientific understanding of causation, includes i) harms to marine natural capital (ecosystem services) from MNP and associated chemicals, ii) harms to human health from chemicals other than bisphenols, phthalates and flame retardants iii) harms to tourism from macroplastics. Social costs associated with marine natural capital (more than US$100 billion per annum) dominate this category, while harms to human health are estimated at US$10-100 billion per annum and harms to tourism up to US$10 billion per annum ranges.

Apples are wrapped in plastic at a supermarket on July 31, 2017 in Pattaya,Thailand. Photo credit: Paula Bronstein/Getty Images.

LEGAL PATHWAYS TO LIABILITY

This chapter summarises, at a high level, analysis prepared by global law firm Clyde & Co on liability risks arising from the manufacture, distribution, use and disposal of plastic. See Annex 2 for the full discussion.

The legal analysis prepared for this report considers the legal principles and emerging trends relevant to the development of plastics litigation in the next five to ten years. It assesses the prospects of claims activity related to bodily injury, property damage and environmental contamination caused by plastics and the chemicals associated with them. The analysis also considers the potential for companies and their directors to be held liable for misleading public statements which they might make about plastics use and sustainability. As it is impossible to be exhaustive, the report focuses on the four centres of environmental litigation: the United States, England, Europe, and Australia.

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Plastic bags and other debris catch onto railing of bike path after a big rain storm that raised the river water along Ballona Creek. Culver City, Los Angeles, California, USA. Photo credit: Citizens of the Planet/Education Images/Universal Images Group via Getty Images.

General insights

The nature of plastics litigation is likely to differ between countries. In the US, with a well-funded plaintiff bar strengthened by an active market for third party litigation funding, damages claims are the paramount form of redress. In Europe, public interest litigation tends to be sponsored by non-profit consumer associations and NGOs whose interest lies less in seeking damages and more in changing behaviours. England and Australia experience both trends: third party litigation funders and NGOs are equally active sponsors of environmental litigation.[61]

Across the four countries there is a considerable divergence of legal theories and regulations, with far-reaching implications. These include:

A. Causation.[62]

Proof of causation is fundamental to any mass tort litigation, particularly where the allegedly harmful product is widely used and/or there are many sources of exposure. A successful claimant will likely need to prove that 'but for' the defendant's activities, the claimant would not have been harmed. This is often a challenging threshold if the defendant's activities represent just one of many sources of exposure to the same harmful substance. The traditional theory gives rise to the perverse consequence that, if a form of wrongful conduct becomes sufficiently ubiquitous, nobody can be held to account for its commission. The wrongdoer can simply "shelter in the crowd". In the last twenty years, courts in the US and (to a lesser extent) England have acknowledged that the traditional theory fails when there are multiple wrongdoers all contributing more or less equally to the same harm. There are alternative theories of attribution such as "market share" (producers being held liable in proportion to their share of total manufactured product) and "material increase in risk" (the defendant's wrongful conduct being treated as a cause of harm if it made the harm materially more likely to occur). These remain relatively novel developments, and it remains to be seen whether alternative causation theories will be taken up more widely. Finally, in the US, environmental tort litigators have begun aggressively and successfully to use public nuisance doctrines, where the thresholds of causation can be less strict and based on unreasonable interference with a "public right" (e.g., to health).[63]

B. Burden of proof.[64]

The rules of causation are closely related to the burden of proof. Usually it is the claimant who bears the burden of proving causation, but in some cases that burden is reversed. For example, Dutch law applies a reversed burden of proof in certain employers' liability cases, transferring the burden of disproving causation onto the employer.

C. The availability of collective redress procedures.[65]

One of the key reasons why mass tort litigation has flourished in the US is the class action procedure and the advent of multidistrict litigation in the federal court system. Class actions are powerful forms of redress for activities, such as environmental torts, which are alleged to have harmed large numbers of people. Class actions are highly developed in Australia, and it is no coincidence that Australia has the world's second highest number of climate liability claims after the US. In Europe, class actions are in their infancy. Significant change is expected in the next two years as an EU Directive on new forms of collective redress comes into force. The next five to ten years are likely to bring a significant increase in mass tort litigation before the European courts.

In the near future, with traditional theories of causation still prevalent in most of the world, plastic-related harms will most probably be litigated in areas where causation can be more easily established (e.g., the realms of employer liability and greenwashing/directors and officers liability) or by pressing legal theories with less strict thresholds for proving causation (e.g., US public nuisance doctrine). Legal theories, particularly those relating to causation, are developing quickly. In the next decade, we expect to see new environmental duties of care emerging and alternative causation theories being more widely adopted. This will make litigation against the producers, distributors and users of polluting products easier to pursue. It may be assumed that class actions will prioritise defendants who have large potential market share liabilities (e.g., major petrochemical companies) and/or who are potentially creating short and specific pathways to harm (e.g., brands and retailers).

Specific exposures

A. Bodily injury litigation

Claims can be originated by workers (employers' liability), members of the public (public liability) and/or consumers (product liability).[66] Employers' liability claims are frequently the first claims arising from allegedly harmful chemicals, due to more pronounced and better documented exposures and elevated employer duties of care. Public liability is rarer as, unless the claimant happens to live adjacent to a source of contamination, it is more difficult to identify a single source of exposure or a single cause of harm – although recent successful litigation in the US related to the prescription and supply of opioid painkillers could prove analogous for plastics. If there are multiple causes of the same harm (e.g., between various polymer manufacturers, the users and distributors of the polymers and the landfill sites containing polymers), the application of causation rules becomes extremely complex and each jurisdiction takes its own approach. Product liability claims (often through class action) are an attractive pathway for consumers who can prove the long-term consumption or use of a particular product and suffer from a signature harm associated with that product. Mass consumer litigation of this nature has recently succeeded on a significant scale in relation to the weedkiller glyphosate.

B. Property damage claims

Claims can be brought by private or public entities whose property has been contaminated by exposure to harmful chemicals such as MNP and/or plastic additives.[67] Such claims are exemplified by litigation relating to MTBE, PCBs and PFAS, where municipalities have claimed the cost of decontaminating public drinking water. Other types of claim might arise from the perceived connection between microplastic-related pollution and the declining productivity of agricultural land. The capital costs associated with decontaminating public drinking water can be very high[68], potentially leading parties to attempt at least partial recovery through claims based on nuisance and negligence, either individually or as mass actions. These claims can be affected by the same difficulties of causation which apply to injury claims, unless a pollution pathway leads to an individual source, the pollutant carries a fingerprint which is attributable to a particular manufacturer, or a court is willing to apply a market share theory of causation whereby each manufacturer of a particular product is held to account for its contribution to the total product in circulation.

C. Environmental claims

Claims can arise from contamination of natural resources by plastics and associated chemicals.[69] Claims can arise from the remediation of the environment and the economic losses resulting from such events. Since natural resources, in most cases, do not have legal personality, and private persons cannot sue in their name, enforcement of environmental laws are mostly the responsibility of government. Should the applicable threshold of causation be crossed, government agencies typically have wide remedial discretion, including the shuttering of harmful operations, and the remediation of land (including the full or partial recovery of costs thereof).

D. Misleading behaviour, breach of consumer protection laws and/or loss of shareholder value claims

Claims can arise from the manufacture, sale and supply of plastics.[70] There are many precedents for this type of claim, from 'greenwashing' claims (giving misleading investor and public statements about the properties of plastics and associated products) to consumer class action complaints and investor lawsuits. The common feature of such claims is that they involve misrepresentations made to a particular class of the public concerning the characteristics of a company or its products. The most likely pathways are liability claims brought against a company for misleading advertising and marketing of its product's plastic attributes, as well as liability claims brought against company directors for their personal failure to disclose and manage plastic-related pollution risks in breach of their general duties. Especially in Europe and Australia, "unfair commercial practices" and "greenwashing" are high priorities for regulatory agencies and prosecutors.

Potential accelerators

Corporates and insurers need to carefully track the evolving legal theories[71], practices, protocols and precedents as they pertain to the above-referenced potential claims and liabilities. Developments potentially indicating an increased likelihood of litigation may include:

A. **Advances in science** allowing more precise indication of pollution sources and attribution of harms to causes
B. **Advances in chemical branding** allowing the tracking of commodity chemicals to their producers
C. **Breakthrough cases brought to high-level courts** establishing new precedents in terms of market share liability and/or joint and several liability[72]
D. **Broader acceptance of new causation standards,** such as "market share" and "material increase in risk"
E. **Tightening international standards and regulations**[73], which may act as a catalyst for litigation by imposing standards of liability. For example, if a regulator limits the permitted concentration of a chemical in drinking water, municipal water companies will incur additional costs which they may seek to recover in litigation against polluters or manufacturers of the polluting product. However, regulation can have a chilling effect on litigation by raising standards of behaviour and reducing the risk that a party will incur liability. For example, if the chemical in the example above is banned from sale, the prospect of claims arising from its future use will reduce as a natural consequence of the regulator having achieved its objective of protecting the public from harm.

Cases to watch out for

There are several ongoing court cases which will be significant indicators for the likely development of plastics litigation:

A. The multidistrict PFAS litigation in South Carolina, in which the court will hear both injury claims (predominantly by firefighters who allege the existence of injury as the result of long-term exposure to harmful firefighting foams) and property damage claims (predominantly by water system providers who allege that their supplies have been contaminated by PFAS). The claims are being put against a group of PFAS manufacturers and issues of causation and market share are at the forefront of the case.
B. The ongoing climate liability litigation in the US, in which the claimants seek compensation on a market share basis for property damage and financial losses, alleging that the oil industry systematically concealed known harms. Climate litigation is relevant to plastics litigation in many ways. It involves a similar relationship between tort liability and federal environmental regulation, similar liability theories including public nuisance, and similar causation theories involving material contribution and market share.
C. The German case of *Lliuya v RWE*, in which a Peruvian farmer seeks compensation from a European energy company based on its alleged contribution of 0.47% to global greenhouse gas emissions.
D. The ongoing climate liability litigation in Europe, especially the forthcoming decision of the European Court of Human Rights in *Agostinho v Portugal & Others*, which will consider whether climate change amounts to a violation of basic human rights.
E. The ongoing criminal investigation in which German prosecutors are examining allegations of prospectus fraud by DWS Group. The investigation centres on the 2020 annual report, in which the asset manager declared that more than half the group's assets under management were invested under ESG criteria.
F. The ongoing claim in the English courts brought by ClientEarth against the board of directors of Shell, arguing that their failure to properly prepare the company for net zero puts them in breach of their legal duties.

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A sea-horse sculpture, made with plastic wastes and trashes those taken out from oceans and seas is being displayed by "Washed Ashore" in front of the United Nations (UN) Headquarters in New York, NY, United States on June 08, 2017 during the UN's "The Ocean Conference". Photo credit: Volkan Furuncu/Anadolu Agency/Getty Images.

QUANTIFICATION OF CORPORATE LIABILITY RISKS

The estimates in this chapter regarding probabilities and magnitudes of exposure have been prepared by Praedicat, a liability emerging risk analytics company. The estimates represent one firm's view of the risks involved, not a consensus among multiple analysts. In addition, the numbers have not been verified, peer reviewed, or compared to other risk analyses (should they exist). Whenever appropriate, numbers are presented as distributions. For a technical explanation of methodologies and results, please consult Annex 3.

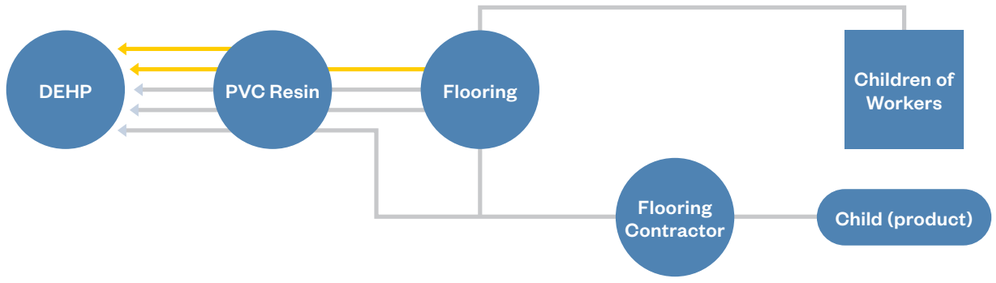
The preceding chapters outline the harms caused by plastic-related pollution and scenarios for potential litigation against the plastic industry. This chapter uses forward-looking liability modelling to estimate plastic-related companies' potential economic liability.

The chapter begins with a summary of the modelling approach used to estimate the plastic-related pollution-driven economic burden to industry ("corporate liabilities").[74] It then describes individual hazards related to plastic and their modelled liabilities.[75] Fully consistent with the analysis of social costs and the analysis of legal pathways, these scenarios concentrate on large, known and emergent harms that have a pathway to legal liability and are most relevant (in terms of potential costs) to both corporates and insurers.

Modelling approach

This analysis describes a number of hypothetical/latent mass torts in terms of the specific hazard, the probable type of plaintiff (e.g., worker, consumer, child), the type of exposure (e.g., factory work, drinking water) and the commercial entities causing this exposure.[76] **Figure 7** presents a sample "litigation map" showing these elements. On the right are groups of plaintiffs. The lines represent potential causes of action, and each passes through circles representing the business activities in the commerce stream, thus representing the naming of multiple defendants associated with each cause of action. The example, from a larger map for diethylhexyl phthalate (DEHP), a plasticiser used in polyvinyl chloride (PVC), shows how litigation involving a plastic additive can draw in multiple industries, and can lead to aggregation risk for insurers.

Figure 7: Sample litigation map segment showing five latent mass actions related to di(2-ethylhexyl) phthalate and flooring-related exposures.



The model considers both the strength and the potential award associated with each of these "latent" torts.

A. **"Case strength"** is calculated by an eight-year simulation model based on current and forecasted science.[77] The model calculates case strength score based on factors such as general causation (Is the alleged hazard capable of causing the injury?), exposure causation (Did plastics provide the exposure pathway?), and signature harms and culpability (Can a specific harm be tracked to a specific source?). Stronger case strength is shown with a colour closer to red, as shown by the yellow lines in **Figure 7**. The model then uses Monte Carlo simulation to generate a range of scientific scenarios, leading to a range of case strength and litigative outcomes.

B. **"Potential award".** If a simulation predicts a litigation event, total expected awards are modelled as a function of the number of people potentially exposed to the hazard, their exposure length, their age during exposure, the date of their joining the action, and the potential size of their individual award.[78]

Plastic-specific exposures

Praedicat modelled the case strength for bodily injury claims from MNP and from several groups of chemicals used in plastic production. These groups included bisphenols (used to make polycarbonate plastic and epoxy resins), commonly used plasticisers (phthalates and their direct replacements like DINCH and N-butylbenzenesulfonamide); and flame retardants (both brominated and phosphate-based).

For each, a brief summary of use and potential exposure is provided, followed by a high-level overview of the simulated liabilities for each of these groups and the industries at risk. Liabilities are expressed at different probability levels, including:

A. **Expected liability:** The mean/average liability across all simulations regardless of whether a litigation event initiates.

B. **Probable maximum liability 1% (PML(1)):** The liability value exceeded by just 1% of simulations and therefore exceeding the other 99%.

The Praedicat model also estimates the distribution of expected liabilities among industry sectors. The analysis suggests that liabilities associated with chemical additives will be greatest for chemical originators (e.g., phthalate producers) as well as the purveyors of the allegedly defective product, while the intermediate chemical and product manufacturers will experience comparatively less risk along the stream of commerce ("U-shaped risk distribution").

Bodily injury from phthalates and other plasticisers.[79]

Without plasticisers like phthalates, plastic would be brittle and easily breakable, so their use is widespread and almost entirely linked to plastics. They are present in bottles, films and sheets (food packaging, construction materials, consumer packaging), wires and cables, flooring, tubes and hoses, and many other applications such as toys and fabrics. Phthalates are also used in rubber, tyres, cooking utensils, food-contact film, bottles, and textiles. Production of phthalates has dropped – they account for 58% of plasticisers globally – but is not likely to drop any further.[80]

Phthalates are in the "known harms" category. There is robust scientific consensus that DEHP, the most common phthalate, is an endocrine disruptor, linked to obesity and to type II diabetes. DEHP has been linked to reproductive injuries (miscarriage in women, reduced fertility in men). Other phthalates with DEHP-analogue chemical structures, such as dibutyl and diisononyl phthalate, are suspected to have similar effects on humans.

In addition, there is a wide spectrum of diseases that may be caused by phthalates, including liver cancer, neurological injury, developmental effects, spontaneous loss of pregnancy and foetal growth restriction. Maternal exposure to phthalates has been linked to altered psychomotor development outcomes in their children.

DEHP accounts for one-third of the total plasticiser market in 2022, with the bulk of production in Asia. While increasingly regulated in Europe, US authorities continue to permit its use in food applications.[81]

The model predicts a high probability of litigation, with a total expected US industry liability of US$18 billion over the next eight years, with a PML(1) of US$129 billion. Phthalate manufacturers are forecast to face the highest liability, followed by producers of food and food packaging, and PVC manufacturers.

Bodily injury from bisphenols.[82]

Bisphenols form the polymer for the clear and shatter-proof polycarbonates used in reusable liquid containers, consumer electronics, and epoxy resins (sometimes lining metal food cans). They are also present in thermal paper, pesticides, polysulfone plastic, and PVC.

Bisphenols can leach out of plastic. They are in the "known harms" category. There is robust scientific consensus that bisphenol A (BPA) and its first substitute, bisphenol S (BPS) disrupt the human endocrine and reproductive systems, causing obesity and infertility. In response, manufacturers have substituted BPA and BPS with other bisphenols, including bisphenol AF, bisphenol B, and bisphenol F. The toxicology research for these compounds is nascent; however, they have similar structures to BPA and BPS and may thus also be detrimental to human health. This pattern of "regrettable substitution" is common in the plastic industry, applying not only to bisphenols but to all the chemical groups discussed in this report.

Science has linked bisphenols to endocrine and reproductive injuries at high levels of confidence. Confidence about causal links to other diseases is growing, especially prenatal exposure causing childhood lung diseases (wheezing and asthma).

The model predicts a high probability of litigation, with a total expected US industry liability of US$1.8 billion over the next eight years, with a PML(1) of US$36 billion. These estimates include litigation on bisphenol exposures not associated with plastic-related pollution, such as thermal paper. However, it is highly probable that all pathways of exposure

for bisphenol will be considered in a large mass action litigation, since plaintiff lawyers often seek to maximise their return by recruiting as many plaintiffs as possible from all exposure pathways. Bisphenol producers face the highest liability, followed by epoxy resin manufacturers. Producers of food and food packaging, as well as plastic manufacturers, face smaller liability risk.

Bodily injury from brominated flame retardants.[83]

Brominated flame retardants prevent ignition and slow the spread of fires. PentaBDE, which contains five bromines, has been banned since 2005 due to its links to human infertility and impaired neurodevelopment in babies. Before pentaBDE was phased out, it was added to flexible polyurethane foam in aeroplane seating, automotive seating, upholstered furniture, mattresses, and carpet padding. Because brominated flame retardants are highly effective at preventing fires, most replacements for pentaBDE are other brominated chemicals. Some of them, such as octabromodiphenyl ether, are similarly toxic to pentaBDE. Others, like decabromodiphenyl ether, are highly persistent in the environment and in animals. Brominated analogues of BPA and DEHP are also substitutes, with the known problems associated with this class of chemicals.

PentaBDE flame retardants cause "known harms", with robust scientific understanding of their link to reproductive and developmental injury. Other harms are under investigation for brominated flame retardants, including celiac disease in genetically susceptible people. There is considerable research underway, especially concerning potential links to endocrine or developmental injury. Case strength scores are low for now, but this could change in the next eight years according to the model's predictions (see Annex 3 for case strength scores and projections).

The model predicts a moderate probability of litigation, with a total expected US industry liability of around US$400 million over the next eight years, with a PML(1) (liability value exceeded by 1% of simulations) of US$10 billion. The manufacturers of the fire retardants face the greatest liability, followed by aircraft manufacturers and operators, and polyurethane manufacturers.

Bodily injury from phosphate flame retardants.[84]

These are an alternative to brominated flame retardants, generally less effective but also less toxic. Used in food-contact material and in polyurethane foam for insulation, mattresses, and upholstered furniture, potential harms are similar to brominated versions, although the bodily injury literature is predominantly animal and *in vitro* studies. Case strength scores are correspondingly low (see Annex 3 for full details), with an associated low probability of litigation and a total expected US industry liability of around US$ 300 million over the next eight years, with a PML(1) of US$4.2 billion. Most of the expected liability is modelled to be borne by the manufacturers of the phosphate flame retardant chemicals and the products containing them.

Bodily injury from MNP.[85]

"Primary" microplastics are produced either intentionally, such as pellets, powders, and beads (intended for use as cosmetic products but banned in the US since 2015), or for air blasting (for paint and rust removal), drug and fertiliser delivery. MNP are also created unintentionally from the breakdown and fragmentation of macroplastic ("secondary" microplastics) via the use and disposal of plastic-containing products. Examples of this include shedding of synthetic textile fibres and abrasion of tyre rubber. Exposure occurs through the air (such as from tyre abrasion), drinking water (groundwater contamination and plastic bottles), and food (plastic containers, fertilisers).

MNP are in the "emerging harms" category, with increasing evidence and intense scientific interest. Modelled general causation scores based on current and expected science are quite high, despite the fact that almost all MNP literature consists of studies *in vitro* (mechanism of injury) and in animals (potential injury). Investigated MNP harms include neurological and developmental injury from congenital exposure including abnormal brain development and renal injury. A transgenerational study in mice found insulin resistance and altered metabolism in the second generation of offspring from exposed mice. Only two epidemiology studies have been published that link MNP exposure directly to bodily injury in humans. The first, from 2021, found increased MNP in the guts of people with inflammatory bowel disease. The second, 2022, study found MNP in liver tissue of people with cirrhosis but not in the livers of healthy controls.

However, with a near-universal presence of MNP in the environment, it is very difficult to link bodily injury harms to a specific exposure, and to rule out other causes. Under the prevailing legal theories on causation, this makes litigation and class action challenging, which is reflected in low case strength scores and low probability of litigation. Total expected US industry liability is around US$100 million over the next eight years, with a PML(1) of US$2.8 billion. Importantly though, legal theories of causation are in flux, as is the science of attribution, and cumulative exposure and our understanding of it is increasing. Thus, this class of liabilities could grow significantly over the next decade, and bears careful scrutiny, with plastic resin manufacturers expected to face the highest liability.

Water remediation of MNP.

Bodily injury litigation is one important facet of microplastic risk. However, MNP's omnipresence in water means there is significant risk of liability for property damage due to water remediation requirements in a manner analogous to PFAS litigation in the US.

Probabilistic estimates of loss are not yet available, but scenario-based liability estimates are included here. MNP are present in wastewater streams and drinking water sources. Depending on how plaintiff lawyers and government regulators regard the issue, one or both could become plaintiffs seeking to have plastic manufacturers and users pay for the water treatment upgrades to remove MNP, primarily nanoplastic. Remediation of nanoscale particles requires expensive treatment such as nanofiltration or ultrafiltration.

In a conservative scenario, where 50% of wastewater and 40% of drinking water volumes require treatment for 15 years, the costs are estimated at around US$180 billion wastewater and US$160 billion for drinking water. The high end estimates cover 20 years of operating costs and twice the volume of remediated water, yielding US$470 and US$430 billion for wastewater and drinking water, respectively.

The industries expected to bear most of the costs of water remediation litigation claiming property damage vary significantly based on the liability theories pressed by the plaintiff wastewater treatment and drinking water treatment companies. In one scenario, the majority of the liability is borne by the tyre, paint, and fabric industries – the three most directly responsible for nanoplastic in water. In a scenario where plaintiffs seek to recover from a broader set of representatives of the plastic-related economy, the hardest hit industries are plastic manufacturing and textiles, followed by a more equal distribution among the rest of the plastic-based economy.

IMPLICATIONS FOR ALL STAKEHOLDERS

Exposures to plastic-related pollution and associated liability risks reveal complex, interconnected problems, crisscrossing the plastics supply chain and beyond. Immediate action is required from corporates, their insurers, their shareholders and investors, policymakers, regulators and supervisors.

A plastic bag hangs in a tree in Lower Manhattan, January 15, 2019 in New York City. Photo credit: Drew Angerer/Getty Images.

Corporates

All aspects of corporate participation in the plastics value chain should be driven by a sincere and precautionary focus on harm reduction, reflected in the approaches companies take to product design, R&D, public communication, transparency and compliance. Companies must clearly disclose where their business has exposure pathways to plastic-related pollution. They should inform customers and the public on safety-relevant properties and the safe use and disposal of products, and take responsibility for chemical management throughout the lifecycle of plastics.

Reducing harm and exposure could include:

- For MNP, phasing out all intentionally added microplastics (especially in personal care products), and committing to the reduction of textile shedding, tyre abrasion and toxicity. In the short-term, producers of primary polymers, brands and retailers can contribute to the development of consistent measures of shedding and abrasion, followed by commitments to minimum standards that phase out the worst performing materials and most hazardous additives. In the medium term, all companies in the value chain should transition to sustainable alternatives (e.g., materials that biodegrade naturally in the marine environment and cannot transport toxic chemicals).
- For macroplastics and greenhouse gas emissions, making a genuine commitment to a circular, non-toxic plastic economy. Corporates should support measures that reduce disposable plastics (including the substitution of plastic-based packaging concepts where feasible), deliver adequate waste management and collection infrastructure (e.g., through extended producer responsibility schemes) and eliminate poor practices (e.g., abandoned fishing gear). They should support ambitious targets and standards for recycled content, product recyclability, and product reuse.
- For chemicals, ceasing all use of substances with adverse health associations in consumer goods (including food-contact materials, clothing, cosmetics and children's toys), and adopting a precautionary approach to substitutions in which safety is rigorously assessed prior to registration or use. Plastic chemicals belonging to classes of chemicals that harm human health should be presumed to carry such risks.

Insurers

The insurance and reinsurance sector can affect the pace of harm reduction through their practices of underwriting, risk management, exclusions and tailoring policy terms. They must begin by assessing their exposure to plastic-related risks, including all those discussed in this report, noting that exposure to plastic-related risk is highly prevalent in the economy and is not limited to the handful of industries that manufacture resins or their precursors. Once insurers have a full view of potential exposure in their policy portfolio, they are also in a strong position to:

- Transfer knowledge to corporate clients about emerging risks and (fully modelled) scenarios, thus elevating the awareness of plastic-related pollution risks at senior level and helping clients develop plans to mitigate exposure and manage transition risk.
- Improve standards on consumer protection, which clearly lowers liability exposure and is thus in the insurer's best interest. Insurers can provide a rigorous quantitative foundation on emerging risks and scenarios to legislators and regulators, especially on the health impacts of chemical and microplastic exposures.
- Influence the international frameworks for plastic management and risk reduction, especially by informing the development of a strong legally-binding instrument that addresses the full lifecycle of plastic, currently being negotiated. In particular, insurers have much to contribute by conveying the human health harms, social costs, and liability risks presented by plastic-related chemicals and MNP. Insurers could also contribute to development of comprehensive reporting and monitoring standards that help to manage and mitigate risk.
- Innovate their coverage products with an eye toward disincentivising harmful behaviours and decisions by insureds.

Investors

Shareholders should demand disclosure of their portfolio companies' plastic-related pollution risks. They should be transparent about setting, measuring and reporting targets on plastic-related pollution; these targets should be aggressive and in line with emerging best practice (see above). Performance on these targets would align with their capital allocation and divestment strategies. Investors should promote to legislators and regulators the business logic of circular plastic material management principles. As good corporate citizens, their support of investment practices designed to reduce harm should go beyond their portfolios.

Insurance supervisors

Analogous to the prudential regulatory responses to climate risk, insurance industry supervisors should develop an independent point of view on the potential exposure to liabilities by individual insurers and the industry (micro and macroprudential), and model the risk of disruption to the financial sector from potential large scale losses resulting from plastic-related pollution. Supervisors may, for example, request the evaluation of specific scenarios to test the books. Once the scale of potential exposure is fully understood, supervisors will be able to ensure capitalisation standards meet the actual risks. Supervisors must respond to the relevant evolution in attribution science and in legal causation.

Policymakers

There is an unprecedented opportunity to address the risks and social costs associated with plastic throughout its life cycle. The intergovernmental negotiations towards a global plastics treaty occurring through to the end of 2024 present an opportunity to (i) establish a global set of precautionary standards, especially on human health impacts from MNP and chemical additives; (ii) advance efforts on reuse/reduce/recycle in ways that increase safety while promoting effective circular plastic management practices; (iii) implement reporting and monitoring standards and requirements that can support risk management and reduction; and iv) implement an effective science-policy interface to support the co-evolution of policy-making and scientific understanding.

Glossary

Term	Definition	Example
Baseline burden	The burden to society of an adverse health outcome, loss, or other damage that is within normal ranges	The disability-adjusted life years burden of endocrine disruption in humans
Chemical additives	Chemicals that are added to plastics to give them specific properties. Over 10,000 have been catalogued	Phthalates, used to soften plastics
Consensus on causation	A probability-based assessment of the current confidence that the scientific community has as to whether a hazard causes harm. Specifically, it is based on an assessment of the number of publications showing harm, the quality of those publications, and the relevance of plastic as a pathway.	There is high consensus that bisphenols can cause harm to humans via plastics
Excess burden of harm	The burden to society of an adverse health outcome, loss, or other damage in excess of what is considered within normal ranges, and hypothesised to be caused by the hazard	The disability-adjusted life years burden of endocrine disruption in humans due to bisphenol ingestion
Expected social cost	An assessment of the possible harm to society adjusted for probability	The social cost of plastic-related harm to human health caused by bisphenols is estimated as large
Harm	An adverse health outcome, loss, or other damage occuring to a receptor, which is hypothesised to be caused by a hazard	Bisphenols causing harm in humans via plastics
Hazard	Any source of potential harm with a known pathway to cause that harm	Bisphenols used in a plastic drinking container
Likelihood that consensus remains static	A probability-based assessment of how likely the current consensus on causation will stay the same. Specifically, it is based on an assessment of a recent change in the number of publications showing harm as well as how long the harm has been studied	A high likelihood that the consensus that bisphenols cause harm to humans will stay the same
Macroplastics	Plastic that is greater than 5 mm in length	Plastic straw
Micro and nanoplastic (MNP)	Particles of plastic that are smaller than 5 mm (microplastic) or smaller than 0.001 mm (nanoplastic). They are produced or result from the fragmentation of macroplastic	Plastic microfibre
Pathway	The route by which a source and a receptor come into contact	Ingestion
Societal harm	A harm affecting people, nature, or the economy & ecosystem services	Chemical additive harms to human health, nature, and economies
Source	The origin of a hazard	Chemical additives and macroplastics

Endnotes

1 Robustness is defined here as 80% probability of being true (equivalent to IPCC high/very high level of confidence). See Annex 1, section 2.2.2 for methodology, and section 3.2 for results.

2 The four centres of litigation considered for this report are Australia; England and Wales; European jurisdictions, with a focus on Germany and the Netherlands; and the United States. See Annex 2, Part 2, for more detail on prevailing theories of causation in key jurisdictions.

3 See Annex 1, Sections 3.1.1 and 3.2.1 for more detail on these

4 See Annex 1, Section 2.2.1 for methodology, and sections 3.3.1 and 3.4 for results

5 See Annex 2, case studies 1-3

6 See Annex 3, Section 3. Plastic-related chemicals.

7 See Annex 3, Section 3. Plastic-related chemicals

8 See Annex 2, para 162

9 See Annex 1, Section 2.2.2 for methodology, and sections 3.3.2 and 3.4 for results

10 See Annex 1, Section 2.2.1 for methodology, and sections 3.3.1 and 3.4 for

11 See Annex 3, Section 4. Microplastics

12 See Annex 3, Section 4. Microplastics; defense costs and damages for all liability claims in the period 2022-2030.

13 See Annex 1, sections 3.2.2 and 3.3.1

14 See Annex 3, Section 4. Microplastics

15 See Annex 2. Paragraph 161 and 163

16 See Annex 1. Section 3.4

17 See Annex 2. Paras 161 and 163

18 See Annex 2. Paras 161 and 163

19 While traditional advertising liability coverage is not intended to apply to greenwashing, it often does, through additional language which applies to breaches of consumer protection or competition laws

20 While traditional advertising liability coverage is not intended to apply to greenwashing, it often does, through additional language which applies to breaches of consumer protection or competition laws

21 See Annex 3, Section 3. Plastic-related chemicals

22 See Annex 3, Section 4. Microplastic

23 See Annex 3. Section 5. Securities litigation

24 Phthalates only. See Annex 3, Section 3.2. Phthalates and other plasticisers

25 See Annex 3. Section 5. Securities litigation

26 See Annex 3, Section 4. Microplastic

27 See Annex 3. Securities litigation

28 See Annex 3. Remediating nanoplastic from water

29 See Annex 1, Section 4.4 for further discussion of the possible scientific breakthroughs

30 See Annex 2, for further discussion on evolution of legal theories, para 41.

31 See Annex 2, for further discussion on the likely sponsors of plastics litigation and the availability of collective redress procedures, paras 10-26

32 See Annex 2. For further discussion on the effect of regulation on legal liability, paras 43-44

33 See Annex 1, Section 4.1 for further discussion

34 See Annex 1, Section 1.1.2 for a brief description of these, and Section 3.3.2 for assessment of scientific consensus

35 See Annex 1 identification and assessment of these plastic-related harms

36 See Annex 1, Section 1.1.2 for further details

37 See Annex 1, Section 2 for more detail on methodology

38 See Annex 1, Figure 13, sections 3.4 and 4.2.2 for more detail

39 See Annex 1, Section 3.3 for results of changes over time in the number of studies published

40 See Annex 1, Section 2 for a full description of methodology and Section 3 for a full description of the results

41 See Annex 1, sections 1.1 and 3.1.1 for full descriptions

42 See Annex 1, sections 1.1.2 and 1.1.3 for descriptions of the plastic lifecycle and the "leakage" points

43 See Annex 1, Figure 4

44 See Annex 1, Sections 1.1 and 3.1.1 for full descriptions of these

45 Some plastic-related chemicals, such as phthalates, are non-persistent

46 See Annex 1, Section 1.1.2. for a full description of the highly durable and mobile nature of plastic and plastic-related chemicals

47 See Annex 1, Section 3.3

48 See Annex 1, Figure 9

49 See Annex 1, Section 2.2.2

50 See Annex 1, Section 4.3 for a full discussion

51 See Annex 1, Section 2.1 for a full description of methodology and Appendix for the list of harms.

52 See Annex 1, Section 2.1 for a full description of methodology on assessment of harms

53 See Annex 1, Section 4.2.1

54 See Annex 1, Section 2.2.2

55 See Annex 1, Section 2.3 for a full description of methodology on grouping of harms

56 See Annex 1, Section 3 for a full description of results, and Section 3.4, in particular, for the clusters of harms

57 See Annex 1, Sections 3.1.1 and 3.2.1 for assessment results on human-health harms

58 See Annex 1, Section 4.1.3 for discussion of the assessment of harms to nature

59 See Annex 1, Section 3.1.4 for results of harms from carbon emissions and climate change

60 See Annex 1, Sections 3.1.2 and 3.2.2 for assessment results

61 See Annex 2, paras 11-12 for full discussion of plaintiff bar

62 See Annex 2, paragraphs 41-42 "The evolution of legal theories". Also Annex 2 case studies: i) paragraphs 74, 76, 81, 82; ii) "Netherlands: a judicial presumption of causality";iii) "Causation in product liability claims"; as well as paragraphs 106, 114, 132, and 152

63 See Annex 2, paragraph 104 for a discussion on US public nuisance doctrine

64 See Annex 2 case studies, paragraph 101 and "Netherlands: a judicial presumption of causality"

65 See Annex 2, paragraphs 19-26 for full discussion

66 See Annex 2 for three case studies/scenarios on bodily injury claims

67 See Annex 2 for case study/scenario on property damage claims

68 See Annex 3, Section 4.3. Remediating nanoplastic from water

69 See Annex 2 for case study/scenario on environmental damage claims

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70 See Annex 2, for two case studies on misleading behaviour, breach of consumer protection laws and/or loss of shareholder value claims

71 See Annex 2, “The evolution of legal theories”

72 See Annex 2,“The evolution of legal theories”. Also Annex 2 case studies: i) paragraphs 74, 76, 81, 82; ii) “Netherlands: a judicial presumption of causality”; iii) “Causation in product liability claims”; as well as paragraphs 106, 114, 132, and 152.

73 See Annex 2, paragraphs 43-59 “The effect of regulation on legal liability”

74 See Annex 3, Section 2 for complete description of modelling approach

75 See Annex 3, Sections 3 and 4, for complete discussion of modelling outcomes for chemical additives and MNP

76 See Annex 3, Section 2.1, for full description of Latent Mass Action concept

77 See Annex 3, Section 2.2, “Characterising case strength”

78 See Annex 3, Section 2.3 “Simulating litigation events”

79 For all full discussion of phthalates/plasticiser bodily injury risks, see Annex 3, Section 3.2

80 Wood Mackenzie *Chemical Industry Report,* 2022

81 Wood Mackenzie *Chemical Industry Report*, 2022

82 See Annex 3, Section 3.1, for a full discussion of bodily injury risks from bisphenols

83 See Annex 3, Section 3.3, for a full discussion of bodily injury risks from brominated flame retardants

84 See Annex 3, Section 3.4, for a full discussion of bodily injury risks from phosphate flame retardants

85 See Annex 3, Section 4, for a full discussion on microplastics

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