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# Plastic pollution, climate change, and essential transparency

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A Viewpoint on the Frontiers in Science Lead Article

Plastic pollution under the influence of climate change: implications for the abundance, distribution, and hazards in terrestrial and aquatic ecosystems

## Key points

- Plastic pollution and climate change are linked through fossil fuels and carbon footprint.
- Although some scientists tend to downplay the severity of climate change and plastic pollution, there is evidence that planetary boundaries for climate and plastic pollution are exceeded and need to be addressed immediately.
- Existing research needs to be expanded to include stakeholders, especially companies, researchers, and policymakers, to find practical solutions.
- Solutions will require integrated approaches that account for the impacts of chemical mixtures and demand transparency about plastic composition and additives so that risks can be understood and managed from the outset.

## Introduction

Plastics and climate change are two of the defining challenges of our century, and they are deeply intertwined (1, 2). Both arise from our dependence on fossil fuels, both contribute to destabilizing the Earth system, and both have breached what many scientists describe as the planet's "safe operating space" (3–5). The growing recognition that plastic pollution and climate change act as joint stressors, interacting across terrestrial, freshwater, and marine systems, demands a shift in how we study, regulate, and govern these crises.

In their *Frontiers in Science* lead article, Kelly et al. (1) do a remarkable job of providing a valuable foundation for this effort. Their synthesis clarifies how climate change intensifies plastic pollution—by accelerating degradation, weathering, and transport—and how plastics, in turn, contribute to greenhouse gas emissions throughout their life cycle. These insights strengthen an emerging consensus that the plastic and climate crises cannot be treated as separate issues. Together they form part of a larger system of unsustainable production and consumption that has already pushed most, if not all, planetary boundaries beyond their safe limits.

Building on the planetary boundaries framework (5), Kelly et al. note that both climate change and novel entities, including plastic pollution, are exerting pressure that risks exceeding the Earth's safe operating space.

## Rethinking planetary boundaries

The planetary boundaries framework, developed by the Stockholm Resilience Centre, has tracked nine key processes that regulate Earth system stability (3, 4). Both climate change and novel entities—a category that includes plastics and their chemical additives—I consider transgressed. The transgression lies in the ubiquity of particles and in the thousands of unstudied additive chemicals and contaminants leaching from all plastics. Yet the interactions between these key processes remain poorly understood. As warming and its increased energy accelerate the breakdown of plastic into micro- and nanoplastics, new feedbacks emerge between materials chemistry, ecological function, and climate regulation (6, 7).

These interconnections reveal a more systemic problem: our fragmented scientific approach. Environmental research has historically been siloed into discrete disciplines—chemistry, ecology, toxicology—each illuminating only a part of a global experiment we never intended to run. To understand how plastics and climate change interact, we need transdisciplinary research that spans environmental and molecular chemistry, microbial ecology, atmospheric science, and socioeconomics. Only then can we move beyond isolated findings toward predictive, policy-relevant understanding and solutions.

The planetary boundaries framework divides global issues into convenient categories for conversation, research, and policy. As research and policy mature, the discussion evolves to consider interactions between these categories, which Kelly et al. approach by linking climate change and novel materials (1). An aspirational goal is to understand the linkages between all the boundaries, enabling the formulation of effective solutions. The next step in this process could be to acknowledge that a global crisis exists and that action across all boundary domains is needed immediately. However, key transparency deficits continue to block progress.

When facing such complex challenges, one of the first questions I ask is, "What is missing?" In the case of plastic pollution, a glaring omission is transparency. We know remarkably little about what most plastics are made of. Why, for example, are their compositions often protected as trade secrets, even though the information is already known to competitors? Are trade secrets a way to avoid regulation and consumer or shareholder scrutiny or concern? Are trade secrets serving innovation or simply shielding manufacturers from scrutiny over leachable carcinogens, teratogens, endocrine disruptors, and heavy metals?

The same lack of transparency extends to the intersection of climate change and plastic pollution. Financial and industrial interests still obscure the full carbon costs of plastic production and disposal. Following the flow of money—through subsidized petrochemical supply chains, carbon markets, and waste exports—often reveals how the appearance of progress can mask the persistence of the same unsustainable systems (8). Without open disclosure of plastic composition, life-cycle emissions, and chemical risks, effective governance will remain out of reach.

## Beyond waste

Another overlooked aspect of the problem is the immense stock of plastic not categorized as waste—the infrastructure, packaging, and consumer goods already in use. Every polymer exposed to sunlight, water, or physical stress undergoes a transformation, leaching chemicals into the air and water and generating micro- and nanoplastics long before disposal. Treating only discarded plastics as pollution ignores this slow, continuous degradation that extends across every material we produce and use.

Education and stakeholder engagement are critical. Regulators, industry, shareholders, and consumers alike must understand that plastics are not inert materials but dynamic chemical systems with complex environmental interactions. Recent studies show that plastic leachates can contain dozens to hundreds of compounds, many biologically active and potentially toxic. The combined, synergistic effects of these mixtures remain one of the least explored areas in environmental science (9).

## Beyond research capacity

An obvious research limitation for pollution writ large is the ability to study mixtures of pollutants, especially the dynamic nature of biological impacts as entire systems respond to abiotic perturbations. There is no simple metric, such as the amount of additive, to predict impact. Some additives, including endocrine-disrupting compounds, are six orders of magnitude more potent than others. Consider that no two plastics, even within a category such as polyvinyl chloride (PVC), are alike. In addition to the polymer itself, there are many industry-known intentional additives of unknown purity and unintentional contaminants introduced throughout the life cycle of the product. The vast majority of these compounds have not been studied individually for biological impacts, and none have been studied as mixtures. At this time, it is impossible to generate probabilistic models without data. Mixtures of compounds leaching from plastics represent a research frontier that requires immediate attention.

## Toward integrated action

It is easy to feel daunted by the scale of this challenge. Plastics are indispensable to modern life—lightweight, durable, and essential in medicine, technology, and transport. Yet their persistence, ubiquity, and role as platforms for chemical delivery and uptake make them planetary stressors. This duality clarifies the need for systemic solutions.

The ongoing negotiations for a Global Plastics Treaty offer a crucial opportunity (8, 10). To succeed, such an agreement must couple commitments to emission reductions and circular economy principles with mandatory transparency in plastic composition and chemical additives. Without that, even the best recycling or substitution strategies will reproduce the same hidden risks under new labels.

Science must lead by example, sharing data openly, harmonizing methods, and integrating climate–plastic interactions into Earth system models. The little we already know about the persistence, toxicity, and climatic feedbacks of plastics is enough to justify decisive, coordinated action.

## A call to transparency and accountability

Kelly et al. conclude that "the prospect that the plastics we produce, use and discard today could have global-scale, poorly reversible impacts in the future is compelling motivation to take the appropriate action now" (1). I share that view—and would add that our first step must be transparency. We cannot govern what we do not know. Every actor—scientists, companies, shareholders, policymakers, and citizens—has a role to play in making the composition, carbon cost, and fate of plastics visible and accountable. Only then can we hope to design materials, economies, and societies that remain within the planet's safe operating space (5, 6).

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