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Inequitable distribution of plastic benefits and burdens on economies and public health

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Plastic heterogeneously affects social systems – notably human health and local and global economies. Here we discuss illustrative examples of the benefits and burdens of each stage of the plastic lifecycle (*e.g.*, macroplastic production, consumption, recycling). We find the benefits to communities and stakeholders are principally economic, whereas burdens fall largely on human health. Furthermore, the economic benefits of plastic are rarely applied to alleviate or mitigate the health burdens it creates, amplifying the disconnect between who benefits and who is burdened. In some instances, social enterprises in low-wealth areas collect and recycle waste, creating a market for upcycled goods. While such endeavors generate local socioeconomic benefits, they perpetuate a status quo in which the burden of responsibility for waste management falls on downstream communities, rather than on producers who have generated far greater economic benefits. While the traditional cost-benefit analyses that inform decision-making disproportionately weigh economic benefits over the indirect, and often unquantifiable, costs of health burdens, we stress the need to include the health burdens of plastic to all impacted stakeholders across all plastic life stages in policy design. We therefore urge the Intergovernmental Negotiating Committee to consider all available knowledge on the deleterious effects of plastic across the entire plastic lifecycle while drafting the upcoming international global plastic treaty.

KEYWORDS
plastic lifecycle, human health, environmental justice, plastic pollution, economic inequality

Introduction

Plastic, a synthetic material made from fossil fuels, affects nearly every person on the planet in some way between production and disposal. Most obviously, people encounter plastic in consumer products; it is commonly used in foodware, houseware, textiles, and packaging due to its light weight, durability, flexibility, and resistance to moisture. People also encounter plastic when it becomes waste. Plastic pollution is highly visible and degrades the aesthetic value and health of the environment. Less visible, but still ubiquitous, is human exposure to microplastics, which have been detected in human blood, placentas, feces, and breast milk (Barrett et al., 2020; Zhang et al., 2020; Yan et al., 2021; Leslie et al., 2022; Ragusa et al., 2022).

All the ways in which plastic affects human and natural systems is not yet – and may never be – fully known. However, a growing body of research reveals that plastic both benefits and burdens stakeholders and communities around the world (Law et al., 2020; Owens and Conlon, 2021).

These benefits and burdens are not distributed equally. For instance, in fossil fuel extraction and petrochemical manufacturing, many stakeholders (*e.g.*, consumers) experience short-term benefits (Healy et al., 2019; Muttitt and Kartha, 2020), and some stakeholders (*e.g.*, industry executives and shareholders) experience substantial economic benefits (Healy et al., 2019). At the same time, people living near processing and manufacturing plants incur significant health burdens (Owens and Conlon, 2021). Likewise, poor communities are unequally burdened by plastic pollution, suffering more severe consequences from clogged drainage systems, increases in vector-borne diseases, and reductions in tourism compared to affluent areas (Owens and Conlon, 2021). These well-studied environmental injustices are often described for only one stage of the plastic lifecycle (Nielsen et al., 2020), which understates the full effect of plastic on socio-ecological systems.

For over two decades, national and subnational governments have addressed plastic pollution using regulatory and economic instruments (*e.g.*, bans, fees) and education and outreach initiatives (Karasik et al., 2020; Diana et al., 2022; Global Plastics Policy Centre, 2022). Now, efforts to address plastic pollution on a global scale are gaining momentum. For example, the Basel, Rotterdam, and Stockholm conventions are beginning to control the trade of hazardous plastic waste and additives (Secretariat of the Basel, Rotterdam and Stockholm Conventions, 2021), and the World Trade Organization initiated an Informal Dialogue on Plastics in 2021 to support member nations adopting trade policies on the sustainable use of plastics (World Trade Organization, 2022). Most recently in February 2022, the United Nations (UN) Environment Assembly passed a resolution to create a global, binding legal agreement by 2024 to address plastic across its entire lifecycle. Developing and incorporating a robust understanding of the distribution of benefits and burdens of plastic at each lifecycle stage is essential to ensuring the efficacy of these policy endeavors.

In this paper, we demonstrate the effects of plastic on communities and stakeholder groups by reviewing examples of benefits to and burdens on economies and public health throughout each stage of the plastic lifecycle and across diverse geographic contexts. Examples of specific burdens and benefits were collected during workshops and discussions with legal and policy experts, physicians, biologists, and other researchers comprising Duke University's Plastic Pollution Working Group. The working group includes faculty, staff, and students affiliated with Duke University who are engaged in scholarship on plastic pollution, toxicity, legal and policy frameworks, occupational risks, and environmental justice, largely in the US. Examples identified in this paper are illustrative, rather than representative or comprehensive, and reflect the working group's skewed expertise toward the US. However, these examples demonstrate the significant and varied effects plastic have on different communities and stakeholders. Finally, we discuss solutions that can mitigate some of the societal burdens of plastic and should be considered in the upcoming UN treaty on plastic pollution and in other decision-making processes.

We define seven key lifecycle stages for macroplastics (Figure 1), which are a significant form of plastic found in the environment (van Emmerik, 2021). These stages were identified using the Global Macroplastic System Map from Pew's *Breaking the Plastic Wave* report and the codebook used to characterize plastic policy design from Karasik et al., 2020, and they are consistent with UNEP, 2022. We then describe example benefits and burdens for each of these stages in the following sections.

Benefits and burdens at each lifecycle stage

Production

Benefit

Around the world, communities rely on the petrochemical industry for employment and local economic activity. Globally, the petrochemical market's expected value is 800 billion USD by 2028, growing over 500 billion USD from 2020 (Fortune Business Insights, n.d.). The US is the top oil and gas producing country in the world, and the petrochemical industry in the US brings in over 95 billion USD in revenue annually and provides nearly one hundred thousand jobs (Burns, 2022) in areas that are typically economically disadvantaged. China has the largest petrochemical industry globally, though countries in the Middle East and North

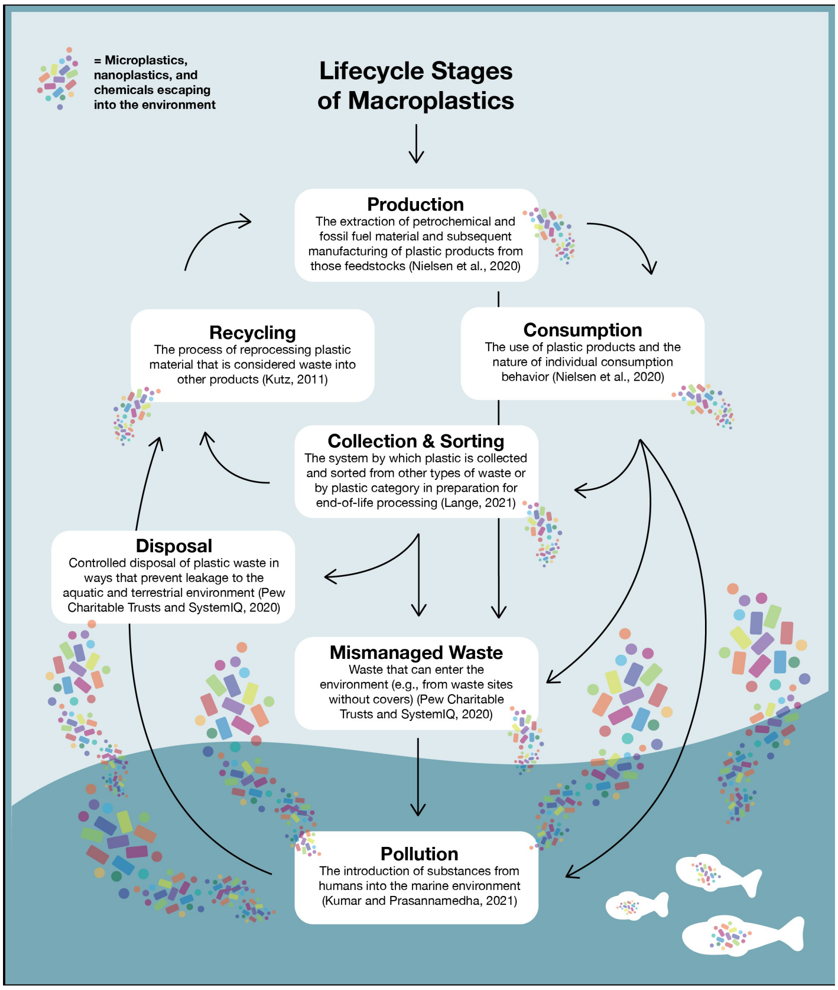

FIGURE 1
Stages of the macroplastic lifecycle.

Africa have a growing share (International Energy Agency, 2018). However, we were unable to find data on the number of jobs and revenue generated in China, the Middle East, and North Africa. Governments continue to invest in the development of petrochemical production despite making commitments to curb climate emissions (Azoulay et al., 2019; Hong et al., 2019; IHS Markit, 2021).

Burden

Communities near petrochemical plants experience substantial health burdens. For example, lung cancer rates in Louisiana's "Cancer Alley" (a corridor between Baton Rouge and New Orleans with over 150 petrochemical plants) are above the US average (Gottlieb et al., 1982; James et al., 2012; Terrell and St Julien, 2022). Similar increases in the incidence of and mortality from leukemia, brain cancer, bladder cancer; non-Hodgkin's lymphoma, and multiple myeloma have been observed in populations living near petrochemical plants in Taiwan, across Europe, and in Nigeria (Domingo et al., 2020). Additional research demonstrates an increased incidence of asthma, negative pregnancy and birth outcomes, and higher rates of attention deficit hyperactivity disorder in individuals living near petrochemical refineries in Taiwan, South Africa, Argentina, Brazil, Canada, Thailand, China, Israel, Italy, and Spain (Marquès et al., 2020; Huang et al., 2022). These studies remain limited and are largely correlational in nature;

without a formal system of epidemiological surveillance for such issues, the true impact remains unknown (Domingo et al., 2020).

Consumption

Benefit

Plastic is inexpensive, can be sterilized and molded, provides a moisture barrier, and has mechanical strength, flexibility, and softness (Sivaram et al., 2021). These qualities make plastic ideal for food packaging and medical instruments where sanitation is essential. Medical devices such as hearing aids, joint replacements, catheters, transparent IV tubes, pacemakers, contact lenses, and straws are often comprised of plastic (US PIRG, 2018). The use of medical plastic rose during the COVID-19 pandemic when medical-grade personal protective equipment proved critical for preventing the spread of disease (Adyel, 2020).

Burden

Over 10,000 chemical additives have been found in plastic products (Wiesinger et al., 2021), of which nearly 25% are considered hazardous to humans if consumed. Women and menstruating people may have increased exposure to plastics with toxins due to higher interactions, on average, with household items and feminine hygiene products than men and non-menstruating people (Park et al., 2019; Ding et al., 2022; Munoz et al., 2022; Upson et al., 2022), further worsening gender-related inequalities (United Nations Environment Programme, 2021, Azoulay et al., 2019). One such additive, Bisphenol A (BPA), is an endocrine-disrupting chemical released from plastic food and beverage containers including baby bottles (Proshad et al., 2018, Zwierello et al., 2020). During consumption, BPA is able to enter human blood or tissue (Kumar et al., 2022), and it can impair the function of multiple body systems (*e.g.*, endocrine, reproductive, renal; Zwierello et al., 2020). It also increases the risk of various chronic diseases, such as breast, prostate, and liver cancers. Investigative research has discovered products labeled as BPA-free still contain BPA (International Pollutants Elimination Network (IPEN), 2022), suggesting that industry efforts to protect humans from BPA exposure are insufficient.

Collection & sorting

Benefit

The collection and sorting of plastic waste is a source of income for both informal and formal waste workers who are paid to collect and sort waste from households or in material recovery facilities. Community-driven material recovery facilities improve solid waste management at the neighborhood scale by formalizing and paying scrap collectors and waste pickers (Budihardjo et al., 2022). For example, in Semarang City, Indonesia, 37 community-driven material recovery facilities with an average of 197 members each collected over 137,000 kilograms of waste from households, offices, and restaurants. This provided up to 37.78 USD in monthly income per person (Budihardjo et al., 2022). Similar social enterprises in Vietnam, Sri Lanka, the Philippines, and Nigeria (Adebiyi-Abiola et al., 2019; Plastic Smart Cities, 2020; Mathis et al., 2022) have created jobs while collecting thousands of metric tons of plastic that may have otherwise been mismanaged (Mathis et al., 2022). Such benefits are not guaranteed, as membership and waste volume must be optimal to ensure sustainability (Budihardjo et al., 2022).

Burden

Formal and informal waste workers focused on the collection and sorting of waste experience occupational hazards. Common injuries include ankle sprains, fractures, ocular trauma, and bites (Dorevitch and Marder, 2001; Battini et al., 2018). Municipal door-to-door waste collectors in Italy have heightened risk of musculoskeletal disorders (Battini et al., 2018) due to handling of waste containers, and waste sorters in southern India reported musculoskeletal disorders and pain in the lower back, shoulder, and neck from manually sorting waste in a squatting position (Emmatty and Panicker, 2022).

Recycling

Benefit

Efforts in the informal sector to support plastic recycling can benefit local economies by fostering entrepreneurship and creating jobs. These social enterprises recycle or upcycle collected waste locally and create local marketable goods, including construction materials, toys, jewelry, furniture, and shredded material for other goods. Effects of these programs have been measured and reported in Mexico City and Toluca City, Mexico (Rivera-Huerta and López-Lira, 2022), Makassar, Indonesia (Kubota et al., 2020), Jenin, Palestine (Bonoli et al., 2019), Port-au-Prince, Haiti (Haney and Bodenman, 2017), and across the African continent (UpCycleAfrica). Such efforts create value for recycled materials, foster a competitive market, employ marginalized people, provide social benefits, and stimulate local economic activity (Mathis et al., 2022: Rivera-Huerta and López-Lira, 2022).

Burden

In recent years, the cost of waste management and recycling for municipal governments has dramatically increased in the US. This is attributed to higher landfill costs (Vedantam et al., 2022), fewer buyers for recyclable material (in part due to China's 2018 plastic waste import ban), and high operational costs for recycling companies (Di et al., 2021). As a result, some US cities have temporarily or permanently suspended recycling programs that reach all households (Corkery, 2019; Cochran, 2020), instead opting for programs where households pay a fee to retain curbside collection services. This fee is an additional cost burden on low-wealth communities and allows plastics producers to evade responsibility for the plastic pollution crisis.

Disposal

Benefit

In many parts of the world, solid waste management services (including landfilling) are contracted out to private or publicly traded firms. Globally, landfill services have a projected value of 149.2 billion USD, with over 40% of the landfilling services market in Asia Pacific and 30% in North America. Comparatively, South America, the Middle East, and Africa combined have under 5% of the total market share for landfilling services. The US has the highest share of the waste management market (24%), and its two leading companies, Waste Management and Republic Services, had a combined revenue of close to 30 billion USD and employed over 82,000 people in 2021 (Republic Services, 2021; Waste Management, 2021). Most of this revenue is from trucks delivering garbage to landfills. Firms participating in waste-to-energy programs, in which methane gas produced in landfills is captured and used as energy, may accrue additional benefits through subsidies (EPA, 2022).

Burden

Microplastics, nanoplastics, and hazardous chemical toxins from macroplastic waste in landfills or disposal areas escape into soil, groundwater, and air (Abiriga et al., 2020; Ozbay et al., 2021). In the US, landfills and other solid waste facilities are often sited in low-wealth and frontline communities (Norton et al., 2007), increasing localized health risks in already marginalized populations (Mattiello et al., 2013; Ozbay et al., 2021). Correlational data demonstrate these risks across the globe (Azoulay et al., 2019); for example, surveyed residents living within 500 and 1,000 meters of a garbage disposal area in Kolkata, India, had high rates of asthma, skin irritation, and gastrointestinal diseases (De and Debnath, 2016), as well as chronic heart, gastrointestinal, respiratory, ocular, and autoimmune conditions (Kar and Basunia, 2020), respectively.

Mismanaged waste

Benefit

The existence of mismanaged waste may encourage the creation of decentralized circular economies (Joshi et al., 2019). One example of this is Precious Plastic, a community-based recycling effort that provides communities with small recycling workspaces to capture, shred, melt, and ultimately upcycle plastic goods, such as water sanitation products (Diehl et al., 2018; Precious Plastic, 2020). This model provides benefits to local economies around the world, enabling communities to create for-profit businesses that generate an average of nearly 7,000 USD annually in revenue from otherwise landfill-bound material.

Burden

In some cases, mismanaged plastic waste is openly burned. Incineration releases particulate matter, BPA, phthalates, and dioxins into air, soil, and water, posing health risks for nearby communities and waste workers (Velis and Cook, 2021; Wu et al., 2021; Ramadan et al., 2022). Studies of open waste burning have measured toxin concentrations at hazardous levels in Abeokuta, Nigeria (Oguntoke et al., 2019); Londrina, Brazil (Krecl et al., 2021); Telok Panglima Garang City, Malaysia (Yu et al., 2022); and other communities in low and lower-middle income countries (Velis and Cook, 2021).

Pollution

Benefit

A growing market exists for ocean plastic as upcycled material in consumer products (Watt et al., 2021). These products often have price premiums and are favorably perceived by consumers (Magnier et al., 2019). Large companies (*e.g.*, Adidas, Coca-Cola, SC Johnson) and small and mid-sized ocean entrepreneurs (*e.g.*, Odyssey Innovation, Triwa) make kayaks, shoes, watches, and backpacks using ocean plastic (Dijkstra et al., 2021). Adidas has sold over 15 million pairs of shoes made of ocean plastic and is expected to generate over one billion USD in revenue from this venture (Aziz, 2018). Another company, Plastic Bank, intends to create a direct market for ocean plastic while addressing poverty: collectors in developing countries are offered digital tokens in exchange for ocean plastic (Katz, 2019). Plastic Bank has engaged with over 500 self-identified communities to exchange currency for ocean plastic.

Burden

Nations and communities that rely on clean marine environments (*e.g.*, tourism, fishing) for income bear the burden of marine plastic pollution. In the Asia Pacific region,

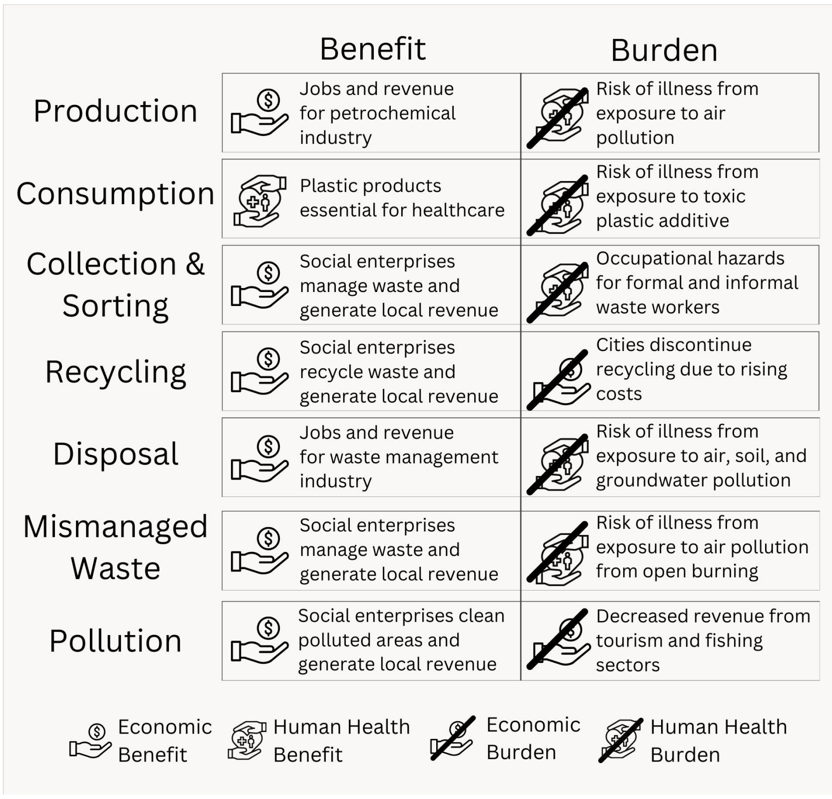

FIGURE 2
Example benefits and burdens across the macroplastic lifecycle. puchongart and WiStudio Elements.

marine debris causes an annual loss of 622 million USD in the marine tourism sector (McIlgorm et al., 2011). A severe marine pollution event decreased beach visitors in Geoje Island, South Korea by 50% over 15 days in July 2011, leading to a loss of 29-37 million USD in tourism revenue (Jang et al., 2014). One study found that reductions in marine debris in the US would generate hundreds of millions of dollars in economic activity from stimulated beach tourism (English et al., 2019).

Discussion

Trends in benefits and burdens

Most societal benefits of plastic identified are economic (Figure 2). Multiple stages of the plastic lifecycle develop and maintain markets and industries that create jobs, generate revenue, and stimulate economies. Some of these industries generate billions of dollars in revenue, in part by drawing on incentives in subsidies, private investment, tax breaks, and public trading (Tickner et al., 2021; Charles et al., 2021). However, such industries increase fossil fuel dependence and contravene efforts to combat climate change (Erickson and Achakulwisut, 2021). Poor communities burdened by plastic waste can incur economic benefits through bottom-up endeavors developed in the absence of state-supported infrastructure, but these do not generate the same magnitude of wealth and instead shift the responsibility for waste management away from producers. Therefore, the economic benefits are not distributed equitably.

Concurrent to the economic benefits of plastic are the burdens on human health at almost every plastic lifecycle stage (Azoulay et al., 2019). Pollution causes nine million premature deaths annually, with an increasing share of those deaths associated with the chemicals found in plastic (Landrigan et al., 2018; Fuller et al., 2022). Because the most at-risk communities tend to be low-wealth and systematically marginalized, people who incur these burdens may not have the means or access to address them (Collins et al., 2016). In most cases, and without substantial litigation, economic benefits from one plastic lifecycle stage are not spent on mitigating the consequential health issues, demonstrating a fundamental gap between who benefits and who is harmed throughout the plastic lifecycle.

In some cases, however, the same stakeholders and communities benefit from and are burdened by the plastic lifecycle. For example, waste collectors and sorters profit off plastic while simultaneously facing occupational hazards. This tension is also evident in areas where petrochemical industries provide employment for communities while jeopardizing their health with air pollution (*e.g.*, Cancer Alley, Louisiana and Houston, Texas). These intertwined benefits and burdens bind communities into systems in which they live, work, and are harmed, complicating efforts to regulate the petrochemical industry through grassroots activism.

Health burdens associated with each plastic lifecycle stage incur significant economic costs on the public. These economic losses are associated with cost of healthcare, loss of workforce, and cost of clean-up. Recent estimates based on limited available epidemiological data suggest that the annual social cost of plastic-related chemical exposure exceeds 100 billion USD and the annual cost of micro- and nano-plastic exposure is 10 billion USD (Merkl and Charles, 2022). Estimates of annual health costs for the effect of prenatal BPA exposure on childhood obesity are over 1.5 billion USD in Europe alone (Legler et al., 2015).

Solutions

Experts suggest the economic costs of health burdens eclipse the short-term economic gains made by plastic manufacturing and waste management industries, though many knowledge gaps of these costs remain (Azoulay et al., 2019; DeWit et al., 2021). Importantly, these costs are not captured in dominant frameworks to inform policy making, such as cost benefit analysis, that can weigh easily quantifiable economic benefits over health data, which remains largely correlative. This merits precautionary approaches to reduce the circulation of plastic and enhance corporate accountability (Figure 3). The precautionary principle in environmental ethics posits that decision-makers can address environmental hazards, despite knowledge gaps, by regulating or prohibiting activities or pollutants to protect human and environmental health (Pinto-Bazurco, 2020). One example in environmental policy is the setting of catch limits in data-poor fisheries based on historic catch only (Dowling et al., 2008), thereby applying the precautionary principal to protect

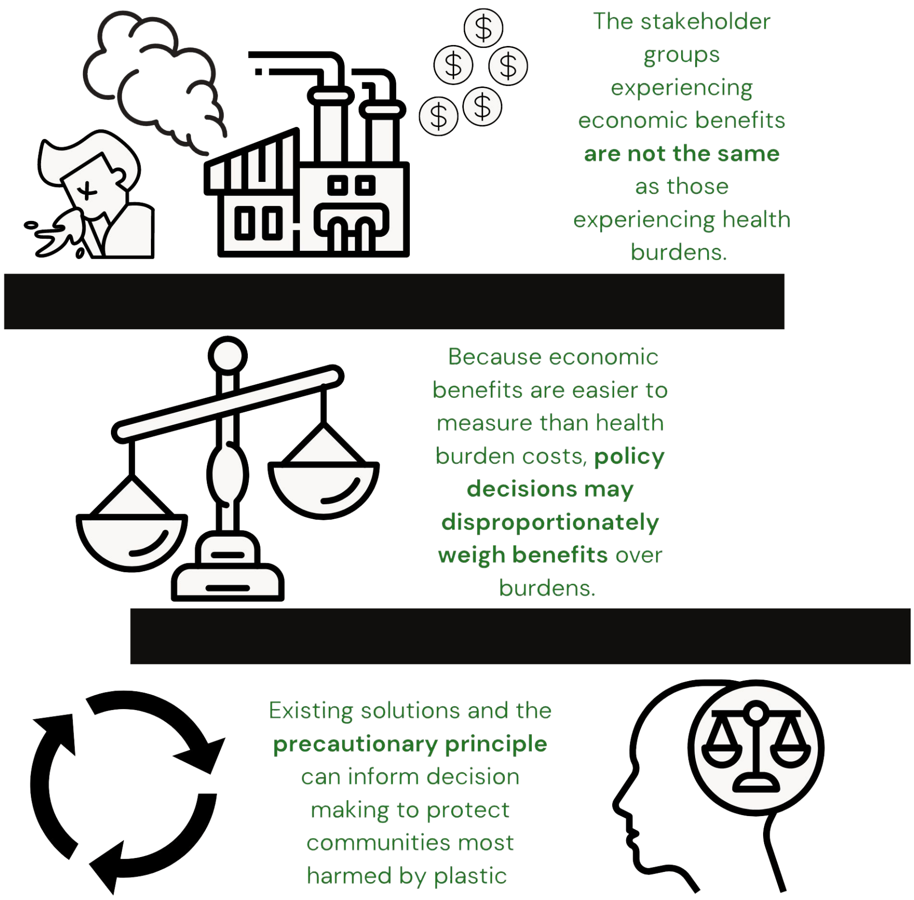

FIGURE 3
Key takeaways from assessment of benefits and burdens. iconsy, ninjastudio, Icons8, narathip, pongsakornjun, anna design A4, and Graphic Nehar.

fish stocks. Although the precautionary principle has not yet been applied to address plastic pollution (Tickner et al., 2021), it would minimize health burdens where causal data or analyses are not yet available (Persson et al., 2022).

Interventions that maximize the efficient use of resources, minimize exposure to toxins, and reduce waste can enable a safe and circular economy (Simon et al., 2021). Proposed solutions include reducing or eliminating toxins and hazards during production, standardizing labeling to inform consumers of toxins and recyclability, and providing incentives for retrieval to remediate ocean pollution (Farrelly and Fuller, 2021). There have been calls for a cap on virgin plastic production to reduce plastic volume from the source (Simon et al., 2021; Bergmann et al., 2022), though such policy reforms must support an equitable transition away from fossil fuels so as not to harm communities reliant on the industry for employment.

The private sector can drive circular economy programs to simultaneously reduce both plastic pollution (OECD, 2022) and negative effects on human health. For example, NextWave Plastics' Social Responsibility Framework seeks to improve and assess supply chain maturity in ocean-bound plastic supply chains for its member companies by emphasizing fair and predictable pay, freely chosen employment, health and safety conditions, strong business ethics, transparency, support for marginalized communities, and prioritized child welfare (NextWave Plastics, 2021). These frameworks enable companies to adopt ethical standards and practices, thereby reducing plastic pollution and alleviating some socioeconomic burdens. However, systems-wide implementation is unlikely without wider participation from governments, the private sector, and individuals.

Conclusion

We provide examples of benefits and burdens of the plastic lifecycle to be considered in the upcoming UN plastic treaty negotiations. Our urgency has limited the scope of the study in several ways. For one, many examples are from the US, highlighting unequal economic, health, and quality of life conditions in the wealthiest country. A comprehensive literature review, supported by stakeholders and experts, will be crucial for understanding the socioeconomic effects of plastic. Likewise, standardized definitions of the plastic lifecycle stages will be essential for the upcoming UN treaty to ensure consistency in national policy implementation and assessment and for clear communication about risks to the public. In addition, humans' relationship to plastic at each stage of the lifecycle is evolving, and the ways in which individuals and communities benefit from or are harmed by plastic will change as new products are invented, or as manufacturing or waste management facilities are established or removed. Evolving benefits and burdens, and in particular their ramifications for population health, must be incorporated into decision-making. As the global plastic treaty negotiations begin, understanding how stakeholders are impacted at each lifecycle stage will increase the efficacy of policy design, implementation, evaluation, and adaptation.

Author contributions

RK conceived and designed the work. RK, NaEL, NiEL, AEB, WE, and KF contributed to the content collection comprising the body of the manuscript. RK, NiEL, and AEB wrote the first draft of the report. NaEL, JAS, and MD-D helped revise the paper significantly. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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