Fighting plastic pollution with a circular economy roadmap and strategy: Addressed to the United Nations Environment Programme

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Executive Summary: Plastic pollution poses a significant challenge to the environment, biodiversity, and human health. Each year, the world produces 300 million tons of plastic waste, equivalent to the weight of the planet's entire human population. Only 9% of plastic products worldwide are recycled due to a pervasive throw-away culture and inefficient policies for managing single-use plastic. Over time, plastics fragment into smaller pieces, distributed across ecosystems by wind and rainfall. Marine and terrestrial wildlife accidentally ingest these smaller plastics, leading to a build-up of toxins in tissues. These toxins are transferred to other species, including humans, through the food chain. This document proposes two policy options to address this issue: (a) replacing conventional plastics with more environmentally friendly alternatives or (b) transitioning to a circular economy focused on reducing, reusing, repairing, and recycling. We urge the United Nations Environment Programme (UNEP) to pursue the latter by leading the development and implementation of a comprehensive global policy agenda for the appropriate and effective management of plastics. This would include the development of financial, environmental, and social estimators to quantify, manage, and reduce plastic waste. A UNEP-led global plastic policy agenda has the potential to standardize and regulate plastic production, consumption, and waste management and ultimately reduce the negative impact of plastics on ecosystems and human health.

I. Background

i. Pollution, the food chain, and risks to human health

Plastics are malleable materials primarily derived from fossil fuels and, to a much lesser extent, from other resources such as plant-based products. Unfortunately, the convenience and low cost of single-use plastics have given rise to a 'throw-away' culture and poor waste management practices. The physical characteristics of plastic products and their degradation period are determined by the type of plastic and the additives used during the manufacturing process (see Table 1). The current chemical components of plastic, the high production and demand for plastic products, and limited waste management strategies contribute to the fact that plastics never wholly disappear; instead, they progressively fragment into smaller pieces (United Nations Environment Programme 2019).

All plastics have become significant pollutants that harm marine ecosystems and threaten human health by entering the food chain (Anela Choy et al. 2019; Jamieson et al. 2019). It is estimated that 13 million tons of plastic waste are deposited into the oceans yearly (Ministry of Environment and Natural Resources 2018a; United Nations Environment Programme 2019). Once plastics reach the oceans, they are exposed to changing temperatures, ultraviolet radiation, high salinity, and the

mechanical force of the waves, which boost plastic fragmentation, resulting in macro (plastic pieces from 5 to 150 mm) and microplastics (plastic pieces < 5 mm) (Campanale et al. 2020). Then, wind and ocean currents can carry microplastics into the marine environment. For example, microbeads from the cosmetics industry and microfibers shed from synthetic clothing can enter the oceans through washing or as waste effluent from sewage treatment plants (Botterell et al. 2019).

Consequently, fragmented pieces of plastic entangle wildlife, causing deformities, asphyxia, and immobilization (Mitchell 2015; Gregory 2009). Marine fauna can also accidentally ingest these pollutants, causing starvation, systemic failure of the digestive tract, and death (Gregory 2009). Organisms higher up the food chain, including humans, ingest the contaminants accumulated in the organisms they consume lower in the food chain. For instance, recent studies have shown that mussels can accumulate microplastics and that crabs that consume these mussels contain these microplastics in several tissues (Farrell and Nelson, 2013). Similarly, studies suggest that, on average, humans ingest five grams of microplastics a week, equivalent to 50 plastic bags per year or one credit card per week (Gruber et al. 2022; Bai et al. 2022). Plastic accumulation in human tissues can result in endocrine disruption, weight gain, insulin resistance, decreased reproductive health, and cancer (United Nations Development Program, 2023). All types of plastic are environmental pollutants and threaten human health.

Plastics can serve as a dispersion medium in land and ocean for contaminants and pathogens through adsorption, leaching, microbial attachment, ingestion, or breakdown. Contaminants can be metallic or organic materials, including polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH), and pesticides such as dichlorodiphenyltrichloroethane (DDT) (Smith et al. 2018; Teuten et al. 2009). These pollutants are known to be toxic and carcinogenic for humans and wildlife. Furthermore, accumulating these pollutants in tissues can lead to respiratory complications, cardiovascular diseases, reproductive disorders, developmental abnormalities, and neurological impairments (Anwarul Hasan et al., 2022; Korrick and Sagiv, 2008). Similarly, recent studies show that bacteria can form biofilms over entire microplastic surfaces, creating an environment where harmful pathogens can thrive, posing risks to living organisms, including humans (Jacquin et al. 2019). The ubiquitous presence of plastics in the environment serves as a dispersion medium for contaminants and pathogens, underpinning prominent health risks for ecosystems and humans

ii. Governance in the plastic era

The United Nations Environmental Programme (UNEP) is the global authority on environmental concerns. Its mission is to lead and encourage partnerships that enable nations to improve their quality of life while caring for the environment. Although UNEP cannot enforce policies in member countries,, UNEP works closely with the private sector, governments, and civil society to divulge and promote the need for a green and inclusive economy to address environmental challenges.

Across the world, individual countries have implemented different regulations to manage plastic waste ("Towards a Global Plastics Treaty" 2023; Ahmadi et al. 2023; Kochanska et al. 2022), and public policy initiatives seeking to combat plastic pollution are often based on marine litter monitoring data, and risk, impact, and life cycle assessments of plastics (Nielsen et al. 2023). These regulations frequently include banning specific types of plastics, establishing recycling programs, organizing community clean-ups, and promoting biodegradable plastics. However, China and the United States remain the world's main plastic waste generators, with some estimates suggesting that each country individually generates more plastic waste than the entire European Union (Law et al., 2020). Therefore, landfills keep increasing their size to store large amounts of un-recycled plastic waste, and areas that were once cleaned are found polluted shortly after clean-ups. Although some legislation has been put in place across several countries, plastic waste management remains a public environmental and health concern, given that millions of tons of generated plastic have overcome the capacity of available regulatory laws and waste management strategies.

In UNEP's efforts to encourage resource-efficient economies and strengthen environmental governance, the circular economy concept has been

formulated as a promising approach to managing environmental challenges. Yet, it has been highly contested, primarily due to the complexity of its implementation. A circular economy is a production and consumption model that minimizes waste by sharing, reusing, repairing, leasing, refurbishing, and recycling materials and products to extend their life cycle. Specifically, the objective of a circular economy is to minimize consumption and waste without compromising economic competitiveness, and it is not limited to reducing, reusing, and recycling (Kulakovskaya et al., 2023). In this article, we aim to describe policy options for the UNEP, including replacing conventional plastics with more environmentally friendly alternatives and transitioning to a circular economy to address global plastic pollution in developed and developing countries.

II. Current Approach to Address Plastic Pollution

i. Is recycling enough by itself?

The three R's of recycling — reduce, reuse, and recycle — are well-known. While recycling is often touted as an efficient way to tackle plastic pollution, when considered the primary tool to address plastic pollution, recycling's limitations must be taken into account (Hahladakis et al. 2018; Hopewell, Dvorak, and Kosior 2009; Emily J. North 2013; Main 2023):

- Not all types of plastic can be recycled.
- Plastic must be in a pure state to be recycled. Once mixed with glues, resins, or other substances like aluminum, plastic cannot be recycled.
- If plastics are exposed to sunlight for prolonged periods, they cannot be recycled due to ultraviolet damage.
- Some plastics with an unknown composition (i.e., those combining different types of plastic), identified with symbol 7, are difficult to recycle.
- Some plastics, like PVC, release toxic compounds during recycling.

Nations primarily rely on recycling as a solution to plastic pollution, while adopting effective recycling methods across developed and developing countries remains a significant challenge, particularly for vulnerable communities that require substantial support to manage their waste. Globally, only 9% of plastic is recycled, while 12% is incinerated, and 79% ends up in landfills or is dumped into natural ecosystems (United Nations Environment Programme 2019). Recently, chemical recycling emerged as a promising approach to recycle contaminated or degraded plastics that cannot be recycled through traditional methods, ultimately converting waste into its original chemical building blocks (Chen and Hu, 2023). However, this process can create large amounts of toxic waste that are harmful to humans, and that there are large corporations with misleading advertisements that may not perform recycling ; and instead choose to incinerate plastics (Noor 2024). Due to the inefficiencies in recycling, efforts should primarily focus on reducing and reusing plastic consumption, only to leverage recycling as a complementary solution.

ii. Plastic bans and taxes

Around the world, both developed and developing countries recognize the problem of plastic pollution and have proposed legal solutions to address it. For instance, in 1993, Denmark became the first country to impose a tax on plastic bags, resulting in a reduction of over 40% in plastic bag sales in the last 25 years and an increase in the use of reusable cloth bags (Gunn 2018). Similarly, in 2002, Ireland implemented a plastic bag tax to reduce its consumption, leading to a 94% drop in plastic bag use in the country. Over 12 years, the Irish levy on plastic bags generated around 200 million euros, which were used to fund clean-up projects (Rosenthal 2008; Anastasio and Nix 2016). More recently, in 2018, the United Kingdom enforced a ban on microbeads (i.e., plastic particles less than 5mm in diameter) in cosmetics and personal care products to prevent them from entering the ocean and being ingested by marine fauna (Department for Environment, Food & Rural Affairs 2018). Notably, European countries are just some of the countries enforcing legislation to regulate plastic production and consumption.

In Latin America, Chile was the first country to ban plastic bags in supermarkets and convenience stores in 2018 (Bonnefoy 2018; United Nations Environment Programme 2018b), while in Africa, Mauritania established national bans on plastic bag production, distribution, and use in 2013, followed by Kenya in 2017, and Tanzania and Nigeria in 2019 (United Nations Environment Programme 2018a). In

North America, Mexico has approved bans on plastic bags in several states, including the capital, Mexico City, since 2018 (United Nations Environment Programme 2020).

Besides specific bans and regulations on plastic, countries have sought to modify how the economy works to create behavioral change at the social and political levels. Therefore, in 2015, the European Union proposed a Circular Economy Action Plan (European Commission 2018) to promote plastic design and production processes that fully respect reuse, repair, and high-quality recycling needs. Specifically, the European Union determined that by 2030, all plastic packaging on the EU market must be reusable or should at least be recycled cost-effectively (European Commission 2018). To this end, taxation and economic instruments reward the uptake of recycled plastics and favor reuse and recycling over landfilling and incineration (European Commission 2018). Similarly, in Latin America, countries like Colombia, Chile, Ecuador, Peru, and Uruguay are developing circular economy proposals prioritizing reusing before recycling. For instance, Chile implemented the Chilean Plastics Pact initiative to ensure that a third of all plastic packaging is effectively reused, recycled, or composted by 2025 (Ellen MacArthur Foundation 2019). In addition, banning plastic bags in Antigua and Barbuda was complemented by tax exemptions for reusable bag imports in 2016 (IETC 2019). Despite the efforts made worldwide to manage plastic waste and to regulate the production and consumption process, plastic pollution still needs to be tackled effectively by considering the social, environmental, and financial needs and strengths of specific countries. The ultimate goal should be to regulate plastic production and cost-effectively reduce its waste.

III. Policy Options

i. Option A: Alternative plastics

UNEP should encourage the development of biobased and biodegradable plastics, which can help replace conventional plastics with more environmentally friendly options. Biobased plastic refers to a polymer derived from a non-petroleum resource, while biodegradable polymers are those capable of degrading faster than conventional plastics by exposure to natural stressors such as UV light and high temperatures or by interacting with microbes, regardless of whether they are based on fossil fuels or not (Wackett 2019). Technological advancements in the chemical composition of biobased and biodegradable plastic materials represent a promising opportunity to reduce plastic waste and greenhouse emissions.

Advantages

Biobased plastics offer advantages over traditional plastics since they are not made from fossil fuels (Wackett 2019). Therefore, their production will result in lower emissions of greenhouse gases. Additionally, biodegradable plastic degrades faster than conventional plastic, reducing landfill accumulation and easing waste disposal. For example, polyhydroxy butyrate (PHB) is a biobased and biodegradable compound belonging to a family of biopolymers produced by bacteria, which can substitute petrochemical-based polymers, especially for thermal containers, single-use plastics, and water bottles (McAdam et al. 2020). As more biobased and biodegradable compounds are discovered, we could produce more eco-friendly materials and leverage their advantages to phase out fossil fuels, reducing greenhouse gas emissions and plastic waste.

Disadvantages

The development and testing of biobased plastics is a complex and costly process frequently associated with higher production costs, low yields, and downstream processing complexity, limiting mass production (McAdam et al., 2020). In general terms, the development process is composed of different stages, including (i) Research and Development (R&D) phase, (ii) Prototype development, (iii) Pilot-scale production, (iv) Testing and certification, (v) Market testing and validation, and (vi) Commercialization and launch. Although the specific cost of these phases varies on a case-to-case basis depending on the complexity and scale of the project, the associated costs are estimated between 1 to 10 million USD in the United States, with timelines ranging from 3 to 6 years. Frequently, businesses and organizations plan for these associated costs, and they leverage private funding, public grants, and strategic partnerships to support the development of new biomaterials. UNEP could play a major role in promoting the development of biobased materials by mediating alliances and strategic partnerships between governments, as well as private funding and public grant opportunities.

Similarly, UNEP should become an external consultant in developing and testing biobased plastics to produce them in large batches without substantially increasing production costs.

Although biobased and biodegradable plastics are more environmentally friendly than conventional plastics, they still pose a risk to living organisms (Gallo et al., 2018). While the concern of landfill accumulation would be reduced by faster fragmentation periods, the generation of macro, micro, and nano-plastics still need to be addressed. Recent studies have shown that the degradation of biobased and biodegradable plastics, such as PHB, does not result in the generation of microplastics but instead creates nano-plastics (particles smaller than 0.001 mm), which also have toxicological effects on living organisms and can be transferred to other species along the food chain (González-Pleiter et al. 2019). Moreover, it has been demonstrated that there is no significant difference in the toxicity of biobased plastics compared to conventional ones (Zimmermann et al., 2020). Therefore, assessing the potential risks biobased and biodegradable plastics pose for living organisms is critical when developing and testing them.

ii. Option B: The circular economy model

Plastic plays a fundamental role in modern society, from agriculture to the healthcare industry. Its global market value is expected to reach 754.3 billion US dollars by 2027 (Garside 2020). Therefore, it is essential to adopt a circular economy model that aims to reincorporate all materials labeled as waste back into the production process, contributing to the sustainable development goal of responsible consumption and production. The UNEP and the European Union have made efforts to implement a circular economy model based on the 5 Rs: Reduce, reuse, repair, regulate, and recycle.

Advantages

A circular economy is an industrial economic model that has emerged as a resilient adaptation to climate change (Garcés-Ayerbe et al. 2019; Nhamo and Ndlela 2021; Fiksel, Sanjay, and Raman 2020; Ibn-Mohammed et al. 2021). It is based on six main principles: (i) Efficient product design, (ii) Regulated industrial production, (iii) Distribution, (iv) Regulated consumption, (v) Repairing and reusing, and (vi) Recycling and remanufacturing. So far, most efforts rely on recycling alone. However, with adequate laws that reinforce the reduction of conventional plastic use, encourage the development and production of environmentally friendly materials, promote the reuse and repair of plastics, and establish well-structured recycling and waste management networks, we can reduce greenhouse emissions and landfill accumulation to put our communities on track to becoming sustainable. The circular economy economic model represents a complex yet robust approach to tackling plastic pollution while regulating production and consumption.

There is widespread political and social awareness about the consequences of the throw-away culture surrounding plastics. Thus, many of the necessary elements to lay the groundwork for a circular economy already exist. Although current recycling programs are inefficient, they exist across cultures and communities and will aid in developing a circular economy. For instance, recycling supports resource conservation by preventing the extraction of raw materials from the environment for new products. In addition, recycling can contribute to creating a closed-loop system in a circular economy by incorporating recycled materials into the manufacturing products, reducing environmental footprints. Similarly, scientific efforts seeking to discover more environmentally friendly materials and laws regulating plastic use and production are now a reality in several countries. However, one of the challenges when implementing a successful circular economy consists of providing quantifiable data via objective estimators, such as performance indicators and standardization of quality protocols, some of which have already been developed by the European Commission (Moraga et al. 2019; Mayer et al. 2019). Overall, the components of a circular economy are developing or have been developed to different extents worldwide, but the unification, regulation, and assessment of these components remain a challenge.

UNEP cannot enforce any laws or policies in any member country, as this responsibility relies on the legislators of each country. Therefore, we suggest the UNEP serves as a mediator in the development of local and international legislations on plastics by developing and promoting region-specific recommendations based on standardized criteria and performance estimators, which, according to the

European Commission, include but are not limited to, ease of disassembly metrics, old scrap collection rate, recycling process efficiency rate, end of life recycling rate, material circularity indicators, total restored products, and value-based resource efficiency, among others (Moraga et al. 2019; Mayer et al. 2019). The first step in this process is that UNEP becomes responsible for developing standardized quality protocols and the corresponding performance indicators to unify the elements of a circular economy, considering the financial, environmental, and social impact of future policies based on the circumstances of specific countries. Then, through strategic partnerships and collaborative international efforts led and coordinated by UNEP, these policies should be implemented across countries based on their specific strengths and limitations supported by monitoring frameworks. UNEP should serve as a consultant, advisor, mediator, and promoter for member countries to develop personalized policies and strategies to implement and monitor a circular economy. Each member country is responsible for enforcing the adequate adoption of these policies, and UNEP should provide constant feedback and recommendations to countries based on performance indicators. Overall, UNEP should lead and mediate the transition to a circular economy on a case-to-case basis for each member nation, proposing standardized protocols, key performance indicators, putative transition timelines, budgeting, and providing advice.

Disadvantages

Transitioning to a circular economy is challenging, especially for vulnerable communities and developing countries. Implementing a circular economy requires significant political and social effort that involves collaboration between citizens, industries, and governments. Some of the most common challenges faced by countries when trying to transition into a circular economy include (i) Infrastructure and investment, (ii) Consumer behavioral change, (iii) Weak regulation and policies, (iv) Supply chain management, (v) technological limitations, and (vi) Social equity and inclusion (Chennak, Giannakas, and Awada 2023). Countries may have, to different extents, infrastructure available for recycling facilities, efficient waste management systems, and remanufacturing plants. It is UNEP's responsibility to collaborate with member nations to identify gaps in infrastructure, establish country-specific budgets, and lead countries in allocating funds for this matter.

Moreover, a shift in consumer behavior is likely conditioned by cultural norms, habits, and personal preferences. Thus, UNEP should create public awareness of the plastic pollution issue and promote the benefits of a circular economy model. It is each country's responsibility to have incentives that encourage adopting circular practices in the local communities. In addition, UNEP should gather information on the research and innovation required to develop scalable solutions for resource recovery, recycling, remanufacturing, and waste reduction to propose country-specific implementation strategies. Lastly, throughout this transition, using performance social estimators, the UNEP should ensure the benefits of a circular economy are not centralized and are accessible to all community members to limit social inequalities. The challenges faced in transitioning to a circular economy can be mitigated with UNEP's leadership, assessment, advice, and strategic planning based on country-specific needs and strengths.

IV. Policy Recommendation

We strongly recommend Option B: The circular economy model. While the elements of a circular economy are emerging worldwide, such as reduction and repair policies for consumers and manufacturers, bans on specific products, extended producer responsibility, and technological advancements in product design (Rosenboom, Langer, and Traverso 2022), there is a growing need to coordinate efforts to design strategies that incorporate and regulate a circular economy's components for a successful transition to adapt and be resilient to climate change. It is crucial to understand that plastic management and mitigation strategies have been implemented in the past in isolation (Zheng and Suh 2019), severely hindering their capacity to address this issue. One of the key factors in the circular economy model consists of legislation based on standardized criteria and performance estimators to guarantee the successful incorporation of the elements of a circular economy.

The UNEP should become a global leader facilitating this transition by proposing legislation for governments that include standardized quality

protocols and performance estimators that the UNEP can later use to provide advice, support, and supervision during implementation. A typical policy action involves reducing plastic use through taxes on plastic products. These taxes can later serve as funding for future environmental projects, promoting the reuse of waste materials as many times as possible among consumers and within production processes, repairing products, and establishing an efficient recycling network that begins with proper sorting of plastic waste and ends with a redesigned and remanufactured environmentally-friendly product. We strongly encourage UNEP to first work with China and the United States to develop standardized quality protocols and performance estimators since these countries are responsible for most plastic waste worldwide. The UNEP should collaborate with international organizations, governments, and stakeholders to create a global network that shares best practices and addresses the challenges faced by different regions and countries.

Overall, UNEP should develop, in collaboration with member nations, legislation and policies that include standardized quality protocols and performance estimators to build and monitor a circular economy. It will then be the responsibility of each country to enforce the policies developed by UNEP, which would then provide feedback to countries based on the monitoring of financial, environmental, and social estimators. The UNEP has a unique opportunity to prompt and lead the transition to a circular economy and contribute to achieving the Sustainable Development Goals through the regulation, standardization, and monitoring of the elements of a circular economy.

Type of plastic	**Symbol**	**Examples**	**Fragmentation time (years)***	**Metric tons produced per year**
Polyethylene terephthalate (PET)	1	Water bottles	500+	> 56 million
High-density polyethylene (HDPE)	2	Shampoo, milk, and ice cream bottles	300+	> 66 million
Polyvinyl chloride (PVC)	3	Pipes and isolation wires	300+	> 50 million
Low-density polyethylene (LDPE)	4	Supermarket plastic bags and film to pack foods.	55+	> 25 million
Polypropylene (PP)	5	Potato chip bags and bottle caps	200+	> 79 million
Polystyrene (PS)	6	Cutlery, mugs, packaging for take-away foods.	400+	> 15 million
Others (Acrylics, polycarbonates, etc.)	7	Sunglasses and DVDs	100+	Undetermined
**The fragmentation period depends on the size and type of plastic and the environmental factors to which the plastic is exposed.*				

Table 1. Types of plastics (United Nations Environment Programme 2019; Ministry of Environment and Natural Resources 2018a, 2018b; Soong, Sobkowicz, and Xie 2022)

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