Plastic Pollution and the Need for Responsible Plastic Consumption and Waste Management

Faith Chebet Tumwet[1,2](✉) and Traugott Scheytt[1]

[1] Chair of Hydrogeology and Hydrochemistry, Freiberg University of Mining and Technology (TU Bergakademie Freiberg), 09599 Freiberg, Germany
Faith-Chebet.Tumwet@doktorand.tu-freiberg.de

[2] Surface Technology, and Natural Substance Research (ZIRKON), Zittau Institute for Process Development, University of Applied Sciences Zittau/Görlitz (HSZG), Recycling Management, 02763 Zittau, Germany

Abstract. Plastic pollution is a global anthropogenic threat to all environmental compartments. The current plastic waste management practices include recycling, composting, and incineration for energy recovery or deposition in landfills, resulting in leaks into the natural environment at each stage. Interdisciplinary research and innovation perspectives in policymaking connecting the different actors in the plastic value chain would ensure the closure of material loops, safeguard human health, reduce climate change impacts, and promote biodiversity. This short paper provides an overview of the pervasive nature of plastic waste and microplastics in the natural environment, outlining a harmonious, systematic, and collaborative approach to tackling the plastics value chain while offering a potential circularity of material flows aligned with the principles of a circular plastic economy. Finally, a case is made to incorporate sustainable, restorative, and regenerative plastics production, use, and after-use as one of the unique indicators of Sustainable Development Goal 12. Ensuring sustainable consumption and production patterns in the plastics landscape will demand the development of product standards and a holistic assessment methodology to guide the design of circular products, services, and business models.

Keywords: Policy · Soil · Circular plastic economy · Biodiversity

1 Introduction

The United Nations (UN) Sustainable Development Goals (SDGs) were launched in 2015, comprising 17 SDGs, within which 169 targets were outlined to be quantifiable against 247 unique indicators [1]. Goal 12 aims to ensure sustainable consumption and production patterns, and governments and corporations have widely adopted it to improve sustainability. However, with the 17 SDGs being clearly outlined and detailed, the lack of clear indicators for the pervasive global atmospheric, aquatic, and terrestrial plastic pollution could undermine the implementation and achievement of the goals [2].

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Plastics and, specifically, marine plastic pollution are mentioned under Goal 14, "Conserve and sustainably use the oceans, sea, and marine resources for sustainable development", indicator 14.1.1b [1].

As outlined in Goal 12, unsustainable consumption and production patterns lead to climate change, biodiversity loss, and pollution [1]. The unsustainable accumulation of plastic waste throughout its life cycle from energy and material input, production, distribution, use, disposal, and reuse or recycling has often been described as one of the most pressing current environmental challenges [3].

The current plastic landscape presents a linear plastic economy that leads to persistent plastic pollution with detrimental effects on the economy and the environment. Since the beginning of its mass production in the 1950s, about 8300 million tonnes of plastics have been produced. Despite the immense societal benefits, it is estimated that approximately 5800 million tonnes of plastics, representing 70% of the total amount, have become waste, of which 84% or 4900 million tonnes have been disposed of in landfills or the natural environment [3]. Of this, almost 50% is destined for single-use, particularly food packaging [4], leading to unsustainable plastic waste generation.

As shown in Fig. 1, global plastic production was 367 million tonnes in 2020, a slight decrease from 368 million tonnes in 2019, possibly due to increasing bio-based, greenhouse gas-based, and use of recycled feedstock to produce biodegradable plastics [5]. Nevertheless, global production from virgin fossil-based feedstock is expected to double in the next 20 years [6]. Thus, it has become a growing concern and discourse among policymakers, biologists, conservationists, environmentalists, and the general public.

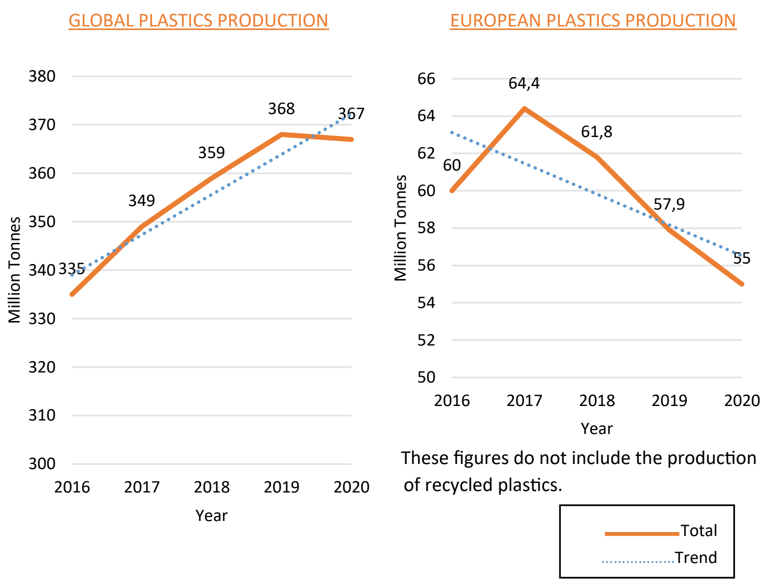

Fig. 1 An evolution of global and European plastics production from virgin fossil-based feedstock adapted from plastics—the facts 2021 [5]

Responsible plastic production, use, reuse, or recycling leads to a sustainable circular economy. The European Circular Economy Action Plan of 2015, in which a circular economy for plastics is detailed [7], calls for policy-supported structural cooperation of multiple stakeholders, e.g., product designers, manufacturers, end users, and recyclers, to ensure the reduction of plastic pollution. A thriving European bioeconomy will help mitigate climate change, biodiversity loss, and pollution while strengthening European competitiveness [8]. This, coupled with Goal 12, would foster holistic monitoring, reporting, and implementation of a circular plastic economy.

The main aims of this short paper are to (1) state how extensive plastic pollution is; (2) outline the ecological effects on biodiversity due to microplastics in soil; (3) identify potential factors that promote a more sustainable circular plastic economy; and (4) bring a particular focus to the need to center plastics and microplastics while implementing the sustainable strategies and action plans.

2 Plastic Pollution

The current plastic value chain requires a foundational change in how innovation and research are conducted to address the opportunities and challenges of plastic pollution. Plastic pollution is intrinsically linked to climate change in its production from virgin fossil-based feedstock, distribution, and the inevitable culmination of its waste in different environmental compartments [9]. Plastic waste is recognized as ubiquitous, relatively non-biodegradable, and almost omnipresent in the earth's ecosystems. As a result, it is considered one of the significant factors in the global decline of biodiversity, posing a major threat to human health [10]. Large numbers of plastics enter the natural environment and are subsequently fragmented, forming small microplastic particles through physical, chemical, and biological processes [10]. Microplastics are plastic particles smaller than 5 mm [11].

It is challenging to quantify and forecast plastic pollution, terrestrial-based to a greater extent than aquatic-based plastic pollution. Ocean plastics can be quantified as floating debris through visual surveys, satellite, and drone imagery [12–14], beach litter through time-consuming manual counting [15], and total plastics through numerical particle tracking and linear mass-balance models [16, 17]. The impediment lies in ascertaining microplastics that result from UV radiation, chemical degradation, and deepsea bottom currents, that ultimately sink to the seafloor [18].

Qi et al. [19] examined the publications on microplastics, entailing 1331 publications published between 2004 and February 2019, and found 71% centered on marine environments, freshwater lakes, rivers, and other aquatic ecosystems, 24% on sediments (from aquatic environments, beaches, and sludge), while only 5% centered on terrestrial ecosystems. There is increased attention on the potential dangers of microplastics in terrestrial ecosystems; however, it still lags. It is estimated that plastic released annually to the terrestrial environment is 4–23 times greater than that released to the marine environment making soil a larger sink for microplastics than marine environments [10]. It is important to note that most plastic wastes in water bodies were initially produced, used, and indiscriminately discarded on land [19]. Therefore, plastic pollution in terrestrial systems should appear in at least one of the 247 unique indicators of the 169 targets outlined in the 17 SDGs placing research and innovation center on the plastic system as currently, the knowledge of microplastics in soils is very limited [20]. Exploring the contamination characteristics and ecological risk assessment of microplastics in soils remains a significant challenge [21].

2.1 Microplastics in Soil

Agricultural soils are considered the most vulnerable to microplastic contamination due to exposure to human activities and the threat to food security, health, and the environment [10]. In agricultural practices, the utilisation of sewage sludge and slurry for crop fertilization [22, 23], as well as plastic mulching [24], directly contribute to the accumulation of microplastics on the soil surface. The concentration of microplastics in the soil is expected to increase as the application of biosolids as fertilizer, plastic mulching, and irrigation with environmental water continues [22, 25]. In agroecosystems, the effects of microplastics in soil may impact the production and quality of crop plants by directly affecting plant development and altering the soil environment in which they are grown [26]. The physicochemical properties of soil can be changed by alterations in moisture and nutrient mobility as microplastics reduce water infiltration [27], exorbitant N mineralization reduces soil pH [28, 29], increases soil temperature [28, 30], and changes in aggregate stability [28, 31].

Microplastics can accumulate in the tissues of plants, posing potential implications for human health and plant performance [24, 28]. Soil organisms like mites, collembola, and burrowing mammals have been shown to ingest microplastics smaller than 1 mm and their additives, leading to increased bioaccumulation of toxic chemicals [32, 33]. Moreover, microplastics can act as carriers of other common soil contaminants such as heavy metals, human pathogens, and organic pollutants.

3 Circular Plastic Economy

The current plastic life cycle is essentially a linear economy based on three principles governed by their design, i.e., extensive waste and pollution, single-use products and materials, and biodiversity loss as plastics enter and disrupt the natural environment [34]. Since the popular recycling symbols and labels ranging from 1 to 7 of the main plastic polymers were launched over 40 years ago, only 14% of plastic packaging is collected for recycling, of which 4% accounts for process losses, 8% for cascaded recycling into other lower value applications and 2% for plastics recycled into same or similar quality applications [35]. Proper management of the after-use pathways for plastics will determine how sustainable their use and production is. The three main types of plastic waste recycling are mechanical, which produces lower quality than virgin-grade polymers; chemical recycling, e.g., solvent-based purification and depolymerisation using chemical agents that can produce virgin-grade polymers and can be complementary to mechanical recycling; and organic recycling and biodegradation [36].

In Europe in 2020, 23.4% of after-use plastics were sent to landfills, 42% were used in energy recovery operations through incineration, and 34.6% ended up in recycling facilities either inside or outside Europe, of which 0.2% were chemically recycled [5].

The evolution trend from 24.5 million tonnes of waste collected in 2006 to 29.5 million tonnes in 2020 of post-consumer plastic waste in Europe was observed, during which a 117.7% increase in recycling, 77.1% increase in plastic incineration, and a 46.4% decrease in the plastic waste sent to landfills prevailed [5].

To accelerate the transition towards a more sustainable circular plastic economy, regulations are required to control how much plastic waste is produced by compelling companies to be responsible for waste treatment or recycling. After-use pathways such as collecting, sorting, and recycling plastics need to be efficient and cost-effective, with the burden falling equally on the manual sorting from the individual and the proper collection and reprocessing by recycling companies promoting economic and environmental benefits [37]. Policymakers are well-positioned to break this impasse by systemically ensuring shared responsibility and accountability throughout the value chain by strict product requirements, extending the producer's responsibility to its product, and taxation [38]. This would urge regulating plastics at different stages in the lifecycle rather than focusing on one stage, which is usually the waste management stage.

Policy tailored toward a circular business model in the plastics industry would require policymakers and the industry to collaboratively share information while protecting intellectual property, guaranteeing information transparency, and maintaining fair competitiveness, to ensure the resultant plastic products, taking into consideration consumer behaviours as a crucial stakeholder in closing the loop is the end user [38, 39].

4 Conclusion and Outlook

Successful implementation of the wider UN SDGs demands systematic solutions. There is an urgent need to develop and implement sound legislation and regulations regarding plastic materials and, subsequently, microplastics in the natural environment. Efforts at standardizing recycling methods and technologies, identifying distribution and waste management gaps, and easing recycling, aid in alleviating the destructive effects of plastic pollution. There is a need to remove the recycling burden from the consumer to the producer while encouraging responsible and sustainable production.

Societal trends, global trade, and new business models cause the plastic landscape to exhibit continuously evolving responses to plastic pollution. Therefore, promoting interdisciplinary research and collaboration, combining insights from environmental, engineering, and behavioural sciences and policymaking will significantly advance the ability to solve the problem effectively. Education, funding for research, and financial incentives for systemic innovation would harmonise towards the explicit goal of a circular plastic economy fostering holistic methodologies that appraise the economic, environmental, and social impacts of different after-use plastic pathways.

Scientific uncertainty of plastic pollution forms a highly complex problem that challenges identifying specific cause-and-effect patterns that inform policy. Therefore, the lack of comprehensive understanding of the sources, fate, and impact of plastic pollution and, inevitably, microplastics on society and the environment should not prevent action from developing and implementing the practical and systematic solution of Goal 12. Supported by research, policymakers should acknowledge the importance of amending Goal 12 to include plastics as climate change, biodiversity loss, and pollution are a consequence of plastics in the natural environment. Ensuring sustainable consumption and production patterns in the plastics landscape demands the development of product standards coupled with a holistic assessment methodology to provide a guideline for the design of circular products, services, and business models.

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