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Review

Circular Economy and Sustainable Development Goals in the Reduction of Global Nano (Micro) Plastic Pollution

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Abstract

The pervasive environmental buildup of plastics is spurred by their ever-increasing usage and enduring nature, presenting a significant environmental challenge confronting contemporary societies. Ecosystems, the economy, and living forms are all susceptible to the adverse effects of the abundance of plastic waste in various environmental matrices. Also, weathering can further break down the collected waste plastics into tiny particles such as nano (micro) plastic, producing massive amounts of plastic waste. A diagnosis of plastic waste proliferation is required for its sustainable management plan. This review presents the role of sustainable development goals and the circular economy concept as promising approaches to plastic reduction. A viable alternative to address waste management and the global plastic pollution challenge is through recycling and BPs. In addition, the study offers insights into instances when these strategies can result in lessening emissions and suggests significant potential for further research that incorporates the circular economy and SDGs to address the prevailing plastic pollution challenge.

Keywords: circular economy, integrate sustainable development, plastic pollution, environmental accumulation, ecosystems

Introduction

The ongoing and rapid rise in plastic pollution is leading to a simultaneous increase in environmental degradation, drawing global attention to the issue. The amount of plastic released into the environment has been steadily rising despite several governmental initiatives recently being implemented worldwide [1, 2]. Global plastic manufacturing surpassed 348 million tons in 2017, according to statistics. 8 million tons of the 280 million tons of disposable plastics produced in 192 coastal nations and areas in 2011 ended up in the ocean [3]. According to predictions, if more action is not taken, the amount of plastic released into the aquatic

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environment annually will increase from 9 to 14 million tons in 2016 to 23–37 million tons by 2040 [4]. About 27.1 million metric tons of plastic waste were collected in the European Union in 2016. 31.1%, 41.6%, and 27.3% were reused, recycled, and disposed of again in a landfill, respectively [5]. Over time, the plastics collected in the environment can break down into tiny pieces, generating microplastics or nanoplastics [6]. Plastic's resilience to natural deterioration and its toughness and durability constitute significant environmental risks [7]. Particularly concerning sustainable waste management, this resistance has emerged as a substantial issue in the waste management process. Problematically, pollution of the natural environment is primarily triggered by the improper handling and disposal of commercial and residential plastic waste. Micro (nano) plastics are entering natural ecosystems through biological activity, mechanical abrasion, and UV radiation. They are additionally introduced through anthropogenic direct release and as unconsolidated, disintegrating products of larger plastics [8, 9]. Moreover, improper handling and disposal of plastic results in excessive accumulation in ecological matrices like landfills, dumps, and oceans [10]. Marine plastic pollution seriously threatens biodiversity since it impacts ecosystems and damages aquatic life and habitats [11]. Climate change is also accelerated by these issues, as well as the uncontrolled production and usage of plastics. Every phase of the plastic life cycle comprises greenhouse gas emissions, with estimates ranging from 1.7 gigatons of CO_2 in 2015 to extraction, transportation, processing, and production [12]. There are approximately 350 species documented as being entangled in plastic waste, and there are several reports of large plastic entanglements involving aquatic life. By 2050, it is predicted that 12000 million tons of plastic residues will be produced, up from about 284 million metric tons of plastic debris produced in 2020 [13]. This is likely to be an emerging issue shortly due to the persistent nature of Micro (nano) plastics in the environment.

The circular economy and SDGs are essential to rectifying this global trend. The foundational concept of the circular economy is that materials should not flow continuously linearly from production through consumption to end-of-life; however, they should loop back into the value chain [14, 15]. According to the guidelines provided in the waste hierarchy, concentrate on increasing recycling and decreasing waste [16]. The SDGs aim to address the most pressing extensive socioeconomic and environmental global concerns through collective decision-making [17, 18]. The goal of optimizing resource utilization is potentially a single concept that merges all definitions. Nonetheless, it is evident that micro (nano) plastics pollution continues to trigger a global depletion of natural resources; therefore, it is reasonable that the SDGs and circular economy should strive to minimize resource exploitation and enhance Micro (nano) plastics pollution prevention [19, 20]. However, considering the serious threats that pollution and depletion pose to the stability of an ecosystem favorable to human flourishing, they need to act toward environmental regeneration and restoration by supporting sustainability from every possible perspective. Consequently, clarifying the interrelationships between plastic pollution, the SDGs, and the circular economy is challenging. This connection between the circular economy and SDGs in Micro (nano) plastic pollution reduction is rarely addressed explicitly [21–23]. This suggests that decreasing plastic pollution overall will also result in a decrease in Micro (nano) plastic contamination. Therefore, a better understanding of the precise relationship between the SDGs and the circularity of plastic products could strengthen research supporting societal initiatives to cut down on micro (nano) plastic pollution. A handful of reviews have been published; however, the majority centered on specific aspects of emphasizing recycling strategies, management strategies for plastic pollution, or current policies. The links, the role of the SDGs, and the circular economy in reducing micro (nano) plastic pollution are not addressed. Such a thorough analysis that compiles all the relevant data is required. From this perspective, this review paper discusses how SDG and the circular economy can be linked to reducing micro (nano) plastic pollution. In addition, it provides suggestions for reestablishing Micro (nano) plastic pollution policies.

Recognition of the Circular Economy and the SDGs Approach to Plastic Pollution Reduction

Positioning circular economy about the more established concept of SDGs has become a dominant topic [24, 25]. A range of SDGs, including soil and environment, climate change, marine water, urban infrastructure, and responsible consumption and production, are linked to the circular economy. Thus, the relationship between the circular economy and the SDGs in minimizing plastic pollution is depicted in Fig. 1. The circular economy is especially promising for accomplishing several SDGs [26, 27]. For instance, the circular economy model's "made-to-be-made again" policy presents enormous opportunities not only significantly to reduce the need for virgin resources but also to rethink the entire process of handling resources and wastes, redesign products to become cost-effective, promote the development of new and innovative technologies, and produce environmentally friendly products. Creating a closed-loop system through the reuse, sharing, repair, refurbishment, remanufacturing, and recycling of material components is the core of the circular economy strategy, which intends to minimize the consumption of natural resources while providing sustainable resource management [28, 29]. Also, the circular economy concept relies on restoring waste, at least in particular, into the manufacturing process to either be used as a resource for the subsequent

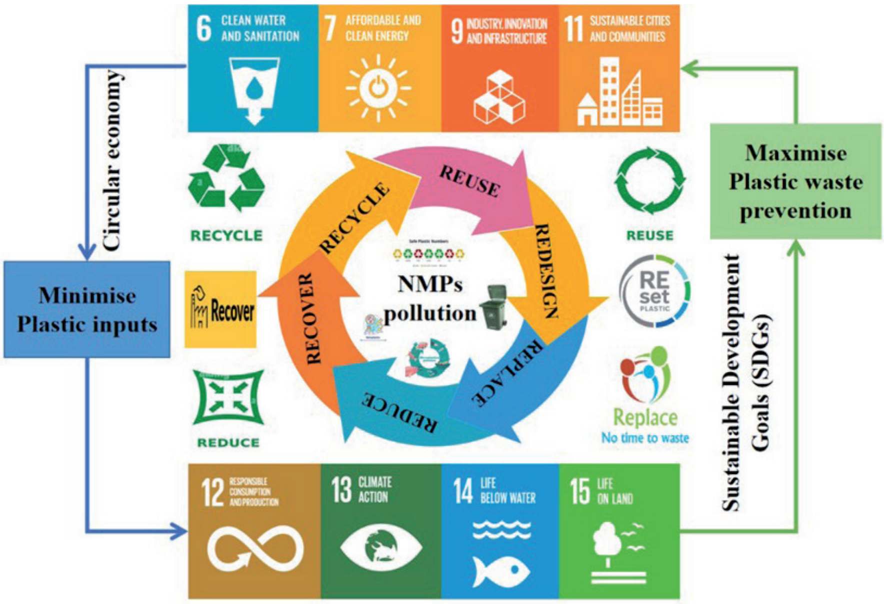

Fig 1. Incorporating circular economy and sustainable development goals approaches the reduction of plastic pollution.

production cycle or directed toward producing an independently new product [30].

Role and Implementation of the Circular Economy and SDGs in Plastic Pollution Reduction

Sustainable Development Goals

The United Nations introduced SDGs following the Millennium Development Goals to achieve sustainability. Many countries have adopted these goals extensively. There are 169 targets and 17 SDGs, yet one of them explicitly addresses plastic pollution [31, 32], which is SDG 14: "*Life Below Water With its target, conserve and sustainably use the seas, oceans, and marine resources"* is focused on minimizing marine microplastic debris loads, especially from terrestrial activities, by 2025 as an indicator [33]. SDG indicators indicate the challenges nations face in pursuing the features and behaviors of plastics in the environment, including managing and monitoring Micro (nano) plastic pollution at the national, subnational, or supranational levels. Therefore, the ensuing subsections address the implementation and role of SDGs in reducing plastic pollution.

SDG 6 (Ensure Availability and Sustainable Management of Water and Sanitation for All)

The concentrations of Micro (nano) plastics depend on the bottle usage frequency and the source of treatment facilities. Micro (nano) plastics in drinking water are consequently acknowledged by the World Health Organization (WHO) to pose potential risks [34]. According to a study, 4.34 plastic particles were identified in every liter of water in 80% of tap and bottled water samples throughout 14 countries [35, 36]. A recent investigation of bottled water discovered that 90% of the samples contained plastic contaminants. More research is being done to document the presence of non-microbial pollutants in bottled and drinking water supplies [37]. Consequently, the Indian government has started the Swachh Bharat Abhiyan, a multi-stakeholder initiative including the public and commercial sectors as well as society, to separate solid wastes, including plastic waste, and clean up cities so that every resident has access to clean water and sanitary facilities [38]. Micro (nano) plastic contaminations are expected to decline when bottled water is clean, safe, and accessible. Further, proper disposal of plastic waste reduces pollution and contamination of freshwater bodies, which serve as drinking supplies for various living organisms [39].

SDG 9 (Build Resilient Infrastructure, Promote Inclusive and Sustainable Industrialization, and Foster Innovation)

Plastic is commonly employed, and finding alternatives would be challenging and time-consuming. Therefore, research and innovation in plastic waste reuse and physical and chemical recycling will be highly beneficial [40]. Since SDG 9 calls for "*building resilient infrastructure, promoting sustainable industrialization, and fostering innovation*", it is imperative that industries modernize and transition to cleaner and more sustainable models. This is due to the need to employ resources more wisely and efficiently. Developing sustainable alternatives, such as biodegradable plastics (BPs), and coming up with innovative ways to handle recyclable materials would take much effort. Currently, just around 2% of plastics are produced using bio-based materials; however, there are a ton of opportunities for advancements and alternatives to conventional plastics [41, 42]. For instance, investigating the extraction of oil through pyrolysis and producing novel byproducts, including plastic wax, which is used to make bricks, tiles, and pavement when mixed with concrete [43, 44].

SDG 11 (Make Cities Inclusive, Safe, Resilient, and Sustainable)

'Make cities and human settlements inclusive, safe, resilient, and sustainable' emphasizes creating more environmentally friendly communities, emphasizing waste management, including municipal and other waste, and air quality. This also encompasses waste generation, resource efficiency, and collection services. Most urban infrastructures, mainly drainage and sewer systems, are becoming clogged with plastic waste due to inappropriate disposal, contributing to widespread plastic pollution and waterlogging [1]. Plastic waste in the marine environment will continue to accumulate if onshore efforts aren't undertaken to improve it; by 2025, it is expected to have increased by an extent of at least ten [45, 46]. To address the issue of plastic waste in water, developed and developing countries need to establish the appropriate infrastructure [47, 48]. As long as migration persists, more people will live in cities, and by 2030, nearly half of all people on Earth will reside in cities or metropolitan regions [49]. As indicated in SDG 11.6, waste management can be implemented to "reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal waste management." Hence, it will be essential to effectively modernize city infrastructure to handle and recycle waste, including plastic. If this is not managed appropriately, the risks related to plastic pollution will increase and affect people's lives and means of subsistence.

SDG 12 (Ensure Sustainable Consumption and Production Patterns)

Numerous studies demonstrate the unsustainable manufacturing and consumption of plastics and the inadequate handling of plastic waste. The annual usage of plastic has surpassed 320 million tons. Around 10% of the waste is recycled, 12% is burned, and the remaining 78% is disposed of in landfills or seeps into the surrounding ecosystem [50]. Oceans consume about 11% of the world's plastic waste, affecting marine ecosystems [51]. Plastic pollution is a complex issue that necessitates an all-encompassing strategy. It is necessary to reconsider the approach taken to address this problem and promote economic growth by first reducing the production of plastics and then increasing the manufacture and consumption of sustainable plastics, particularly single-use, low-value, disposable plastics [52]. Thus, the goal of SDG 12.4 is to considerably decrease their discharge into the air, water, and soil to lessen their detrimental effects on human health and the environment and to achieve the environmentally sound management of chemicals and their wastes throughout their life cycle under recognized international frameworks." Comparably, SDG 12.5 mandates that "*through prevention, reduction, recycling, and reuse, overall waste generation must be significantly reduced by 2030*." These objectives stress the significance of minimizing various waste streams through preventive, mitigation, recycling, and reuse initiatives during a good or service's life cycle [53, 54]. A more sustainable approach would be transitioning to a circular economy, eliminating waste and single-use plastic from the production cycle. It would also emphasize the development of producer responsibility models through innovative product design that would facilitate recycling, reuse, and the reduction of plastic packaging [55]. For practical usage and recycling, the emphasis should be on sustainable manufacturing and consumption practices.

SDG 13 (Take Urgent Action to Combat Climate Change and Its Impacts)

A substantial portion of the plastic's life cycle involves the release of greenhouse gases. For instance, since plastics are made of polymers generated from fossil fuels, many greenhouse gases are released over the product's lifecycle during its manufacture, transportation, incineration, open burning, and disintegration [56, 57]. According to estimates, the world currently emits 400 million tons of greenhouse gases annually over its life cycle. By 2030, that number is projected to increase to 1.34 gigatons; by 2050, it will reach 2.8 gigatons [58]. Promoting required reuse and more ecologically friendly recycling methods rather than burning waste to produce energy is necessary since combating climate change is a significant issue [59].

SDG 14 (Conserve and Sustainably Use the Oceans, Seas, and Marine Resources for Sustainable Development)

Plastic wastes that are laden with various plastics find a path into fresh and marine water's aquatic ecosystems. Aquatic species are suffering greatly from the effects of plastics. Micro (nano) plastics are currently regarded as a global threat because they frequently occur in oceans [60, 61]. The United Nations (UN) highlights that *"conserve and sustainably use the oceans, seas, and marine resources for sustainable development"* is in line with SDG 14, which aims to minimize marine plastic pollution globally [62]. The UN established SDG 14.1 to "prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution, by 2025." Thereby, urgent intervention is required to safeguard the seas for improved marine health, which is essential for accomplishing several other SDGs, such as eradicating hunger and ensuring food security.

SDG 15 (Protect, Restore, and Promote Sustainable Use of Terrestrial Ecosystems; Sustainably Manage Forests; Combat Desertification; Halt and Reverse Land Degradation; and Halt Biodiversity Loss)

The land-based sources of Micro (nano) plastic pollution account for around 80% of the total usage of plastics in terrestrial ecosystems [63, 64]. Although few contemporary studies are available, terrestrial mammals and aquatic organisms absorb plastics. Plastic debris in terrestrial ecosystems is four to 23 times more prevalent than in marine environments [65, 66]. Micro (nano) plastics can potentially impair an organism's fitness and survival ability, and they can build up in casts. Therefore, to maintain and restore the biodiversity of terrestrial ecosystems, it is imperative to investigate the effects of Micro (nano) plastics on aquatic and terrestrial ecosystems.

Circular Economy

A circular economy is one in which the concept of "end-of-life" is replaced with methods of material recovery, recycling, and reduction in the processes of production, distribution, and consumption [67, 68], focusing on minimizing the environmental impact of resource consumption and retaining the materials as long as feasible inside the value chain. This approach will, for the most part, lessen the environmental impact of micro (nano) plastics; nevertheless, there are certain considerations to keep in mind to prevent conflict between the goal of supporting the circular economy and the mitigation of micro (nano) plastic pollution. Future product design research and development should prioritize making things more durable than current single-use items by utilizing new polymers and designing them with reuse and potential recycling in mind. The possible loss of micro (nano) plastics to the environment must be considered throughout a product's life cycle. Additionally, the future generation of polymers should have a significantly shorter environmental turnover duration than current polymers [69]. The prevention of plastics from being released into the environment has been guaranteed by efforts to recycle products consisting of micro (nano) plastics. Extended Producer Responsibility (EPR) should also apply to such initiatives as recycling. As depicted in Fig. 2, the design of new materials and products must be taken into their life cycle rather than in the end-of-life phase and made for reuse and subsequent recycling.

Use of Biodegradable Plastics (BPs)

Plastic manufacturing reached 335 million tons in 2016 and 348 million tons in 2017, which is still expanding globally. Only 0.5% of the 335 million tons of plastic produced annually came from BPs, and by 2023,

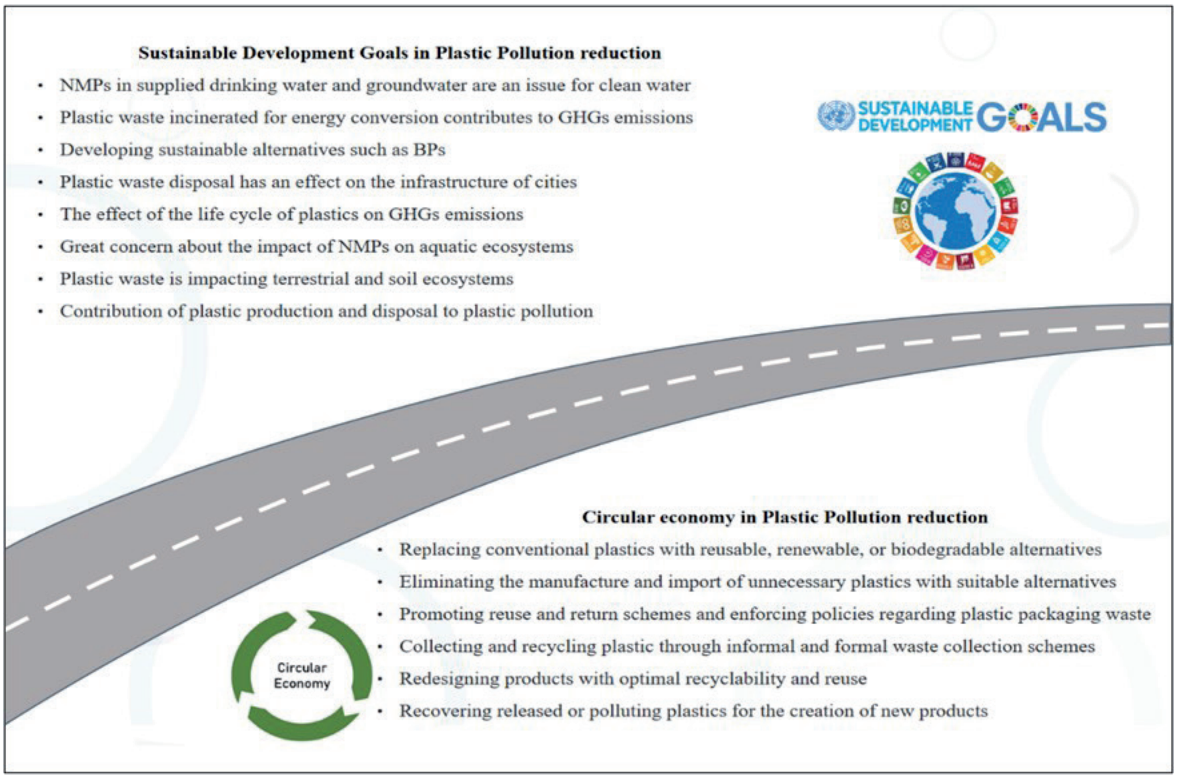

Fig. 2. Sustainable development goals concepts (SDG6, SDG7, SDG9, SDG11, SDG12, SDG13, SDG14, and SDG15) and circular economy, including reduce, replace, redesign, reuse, recycle, and recover as solutions to the reduction of plastic pollution.

that amount is predicted to rise to roughly 2.62 million tons [70]. Even though BP production is still growing, there is nevertheless a drop in the ocean concerning the global issue of environmental accumulation of plastic [71, 72]. The primary factor is expense. Based on the findings, the cost of BPs generated using the current procedure is approximately three to ten times higher than that of traditional polypropylene and polyethylene [73]. Additionally, some BPs are inferior to conventional plastics. Polymers such as polyhydroxybutyrate (PHB) are preferable to commercial plastics in the packaging of oxygen-sensitive items, like food and beverages, since they possess superior barrier qualities compared to PP. However, its low plasticity and impact strength tend to limit its utilization and provide numerous processing challenges when processing polymers [74, 75]. These problems significantly restrict the use and acceptance of BPs, rendering it more challenging to substitute petroleum-based plastics with BPs. Furthermore, BPs appear to be considerably more accessible than their treatment. A polymer needs more energy and effort to degrade, especially compared to conventional plastics, which may also occur on BPs due to environmental factors and chemical composition.

Perspectives for Future Studies

Worldwide interest has been exhibited in micro (nano) plastic pollution research. Various initiatives to expedite circular economy waste management solutions, including novel technology, management techniques, and real-world examples, are being promoted globally by governments, research institutions, businesses, and other stakeholders [76, 77]. It must comprehend and include them and devote the appropriate amount of attention to effective points since none of them could resolve all issues by themselves. Though plenty of current proposals for the 2030 Agenda for SDGs need to be explored about plastic pollution as an emerging pollutant, further research is essential for fully comprehending the principles of the circular economy for the efficient management and mitigation of plastic pollution.

Plastic consumption inevitably harms the environment; however, it should be noted that there are still many fundamental issues that need to be resolved shortly regarding the manufacturing, use, and recycling of plastic waste [78, 79]. The UN seeks to mitigate the effects of ocean acidification, manage marine and coastal ecosystems sustainably, prevent significant adverse effects by enhancing their resilience, and take measures to counteract climate change [80]. Thus, action must be taken to preserve ocean, sea, and marine resources worldwide. The potential socio-economic expenses, losses, and impairments arising from the risks that plastics might be employed are evidence for the necessity for routine monitoring of the distribution and concentration of micro (nano) plastics [81, 82]. Addressing the SDGs and the circular economy might assist in minimizing the environmental impact of plastics, together with legislative action. As environmental scientists studying the effects of Micro (nano) plastics, it is crucial to highlight the need to thoroughly explain the range and depth of negative consequences arising from the plastic pollution disaster, down to the nanoscale, to improve the plastic life cycle. It is also significant that human behavioral awareness changes. Global plastic pollution must be addressed with practical, promising approaches and a shift in human behavioral awareness; the latter will be primarily unsuccessful without the former. Therefore, raising public awareness can be a substitute for using single-use plastics. As a result, both official and informal training may significantly impact recycling and the evaluation of the life cycles of both biodegradable and non-biodegradable plastics. The key to reducing plastic consumption and recycling will involve public and social awareness initiatives to combat plastic pollution. Restrictions on single-use plastics are feasible and crucial, and encouraging alternatives to plastics should be one of the SDGs. As a substitute for plastic, governments must consider bio-based, biodegradable polymers and levy taxes on plastic materials. The marine ecosystem's plastic pollution will decline with the development and application of BPs [83, 84]. Additionally, it is critical to encourage the use of eco-packaging, which will significantly decrease the usage of plastics [85, 86]. Since littering does not alter with adopting adequate technology, we should avoid considering BPs as a technical solution that absolves us of our environmental responsibilities. Unmanaged plastics can take various forms, including open dumping, open burning, and littering, which are more common in rural areas and places with less developed waste management systems. Therefore, enhancing waste management systems and encouraging low-income nations to import environmentally friendly technologies from developed countries may be the solutions to the issue of plastic pollution. Instead of being dispersed haphazardly into the environment, BPs must be regulated.

Conclusions

The anthropogenic era has rendered plastic pollution ubiquitous for human civilization. The manufacturing of plastics is rising sharply, and micro- and nano-sized plastics are primarily responsible for the growing detrimental effects on our ecology. However, the ecological processes of natural environments are adversely affected by both kinds of plastics. Furthermore, plastics can transform into Micro (nano) plastics throughout their degrading process. As a result, these newly emerging pollutants' environmental deposits could potentially occur in lakes, rivers, seas, and other matrices, creating new interactions among the environment and organisms. The more plastic is produced, the more serious this issue will become. Thus, measures should be taken to slow the rate at which plastic accumulates and lessen the ecological impacts resulting from this inevitable accumulation. Even though the goals have not been achieved, many countries have committed to handling the challenge. For improved monitoring, technology transfer, innovations, and cooperation between organizations to take collective action, it is necessary to establish explicit processes to address plastic challenges. In this review, several SDG goals have been comprehensively discussed to reveal their connection to the measures for successfully managing plastics. In addition, it is essential to highlight alternative options and promote research and innovation aimed at reducing, reusing, recycling, and recovering plastics, as well as finding sustainable alternatives. Furthermore, it is imperative to aggressively promote and enforce the awareness and empowerment of communities and citizens to employ collective measures toward minimizing plastic pollution and utilizing alternative plastic approaches.

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Confilict of Interest

The authors of this article state that they have no personal biases or conflicts of interest that could be interpreted as influencing this work.

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