exposure, or they may even increase the toxicity of those pollutants. However, adverse effects of the translocation of vector microplastics, the kinds of ingested particles, the release rate, the clearance time, the quantity of the contamination, its noxious effects, and its translocation in body cells all play a significant role in the chemical release or pathogens adsorption to microplastics [69].

Micropollutant exposure can cause neurotoxicity, which is linked to neurological illnesses. Microplastics can really influence neuronal function and behavior, as shown by in vivo toxicity testing. A decrease in acetylcholinesterase (AChE), oxidative stress with an increment in the quantity of lipid peroxidation and a rise in the anaerobic energy generation are all reportedly caused by microplastics in the brain of Dicentrarchus labrax (European seabass) [99]. Moreover, it has been observed that exposure to PS impairs mouse neurotransmission, altering blood levels of neurotransmitters and increasing AChE activity. About the evidence of neurotoxicity when evaluating microplastics in cells or creatures, it is necessary to appreciate how microplastics might be related with neurotoxicity in people, adding to an increased risk of the development of neurological diseases.

1.5.3 Plastic and Climate Change

Earlier environmental effects research predominantly concentrated on plastic waste's sources, distribution, fate, toxicity, and behavior; narrow attention has been paid to the unignorable contribution of plastic materials to increasing atmospheric GHGs. With the increment in plastic debris, their adverse effects to the planet's climate have increased remarkably. According to scientific studies, each stage of the plastic' life cycle such as extraction and transport of plastics' raw materials, manufacturing, management of plastic debris, and even entering the natural environment contribute to GHG emissions. Hence, despite narrow information on the role of plastics in incrementing atmosphericGHG, the available data imply the fact that GHS emissions from the cradle to the grave of plastic are inevitable and considerable. Plastic's direct and indirect contributions to climate change are demonstrated in Figure 1.8. Common methods to address plastic litter include, landfill, sanitary, recycling, incineration, and so forth. These approaches to plastic waste management directly contribute to GHG emissions.

Recycling plastic debris imply the physical procedure of retrieving material without changing the polymer's molecular structure. Recycling plastic reduces GHG emissions significantly when compared to alternative plastic waste management strategies currently in use. Theoretically, increased recycling might reduce the need for raw materials and prevent emissions from generating the same quantity of raw materials. The US Environmental Protection Agency indicates that recycling 3.17 million tons of plastic debris in 2014 could prevent 3.2 million tons of carbon dioxide emissions, which is the same as removing 670,000 cars from the road for a year. Additionally, recycling plastic packaging could prevent 1.4 million tons of carbon dioxide emissions [33]. Producing new plastic from recycled plastic materials is more than three times more efficient when it comes to GHG emissions than producing the same product from raw materials, which is predominant because original

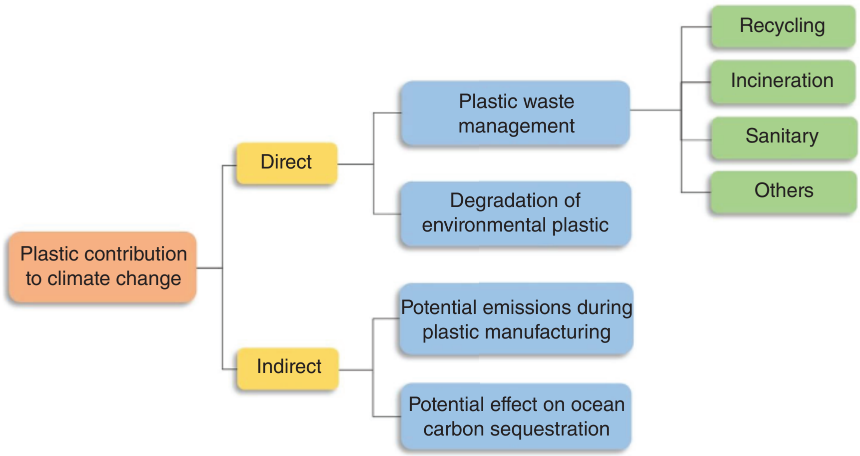

Figure 1.8 GHG emissions in the life cycle of plastic.

products are being replaced and renewable energy is being conserved. However, due to many limitations and challenges, very little proportion of "recyclable" plastic debris is transmuted to the primary goods. Thus, recycling mainly is considered as the primary approach to address the plastic problem has a long-length route.

Recent times have seen incineration viewed as a quick fix for the widespread pollution of land-based plastics. In addition to efficiently reducing plastic pollution, it may also provide heat and energy for human consumption. Plastic debris are converted into combustion gas, fly ash, and bottom ash, during incineration, which also produces heat through burning. In metropolitan regions, collected plastic garbage is burned alongside biomass or fossil fuels in facilities for power generation, waste incineration and other industrial applications, primarily cement kilns, utility boilers, and paper mills. However, burning plastic trash can result in the production of GHGs, often CO_2. Scientific evidence indicates that every ton of plastic packing debris typically contains about 79% flammable carbon, unleashing 790 kg of carbon into the atmosphere, or approximately 2.9 tons of carbon dioxide [100]. More than half of the US's 11 million tons of CO_2e emissions from waste incineration in 2015 (5.9 million tons) originated from plastic waste. The environmental effect of burning plastic garbage in the United States is similar to driving 1.26 million automobiles for each year [33].

Sanitary landfill usually implies the usage of clay or some liners to separate debris from groundwater and put a soil layer to diminish debris exposure to the atmosphere. Emissions of GHG from sanitary landfills are primarily associated with organic waste, including wood, food waste, and paper decomposition. So far, there is no narrative of GHG emissions from plastic landfills. The emission associated with landfill plastic packing litter comes from the treatment and classification of pre-landfill debris and the usage of fossil fuels for the transportation of debris from collection points to landfills. Yet, this does not eliminate the potential of GHG emissions from landfills.

An additional 32% of plastic packing debris is not treated, in addition to the management techniques stated above. Different approaches for unmanaged plastic debris include dumping, littering, and burning that are frequent in regions with underdeveloped facilities for the management of wastes. Nevertheless, the effect of unmanaged plastic debris on global warming is not yet understood completely. Open burning, defined as a technique of burning flammable debris in the environment, severely affects human health and climate due to it occurring at lower temperatures and is conducted with no measures to reduce air pollution compared with a debris incinerator. According to scientific data, each ton of plastic debris emits 2.9 million tons of GHG during open burning [33]. Generally, in general, it is unclear how the open disposal of plastic debris contributes to climate change. Recent scientific studies have revealed that plastic degradation under sunlight in the nonaquatic environment can unleash GHG more quickly than in the oceanic environment [101]. Nonetheless, these emissions' magnitude and annual rate are still yet to be determined. Investigating the amount of GHG emitted from unmanaged plastic waste can show the full harm posed by plastic packing debris to climate warming, despite significantly insufficient data on waste management methods. The effect of unmanaged or mismanaged plastic debris on climate warming is mainly related to the percentage of open burning and, similarly, leads to varieties of worldwide concerns.

Disposing of microplastics will not stop the emission of GHG and the impacts of microplastics on the environment. After exposure to radiation, it was discovered that several of the most popular types of plastic release detectable levels of two GHGs (ethylene and methane). Emission rates for CH_4 are between 10 and 4100 pmol/day/g, and those of C_2H_6 is between 20 and 5100 pmol/day/g [101]. In addition, the emissions of GHG from virgin plastics were much higher than those from old ones. Besides, whereas the emissions of GHG from aged plastic stay constant over time, they rise with time from virgin ones. Anti-ultraviolet plasticizers, which limit the impacts of ultraviolet radiation and delay the degradation process, are likely to be responsible for this. [101]. Compared to other sources of GHG emissions, including industrial processes, vehicle transport, and agricultural operations, the rate of GHG generation from plastic materials may be considered insignificant. However, as plastic manufacturing rises and more improperly disposed of waste plastics, emissions of GHG associated with plastic degradation will probably rise as well, which may be a greater concern [40].

GHGs are inevitably emitted throughout the mining, transportation, refining, and manufacturing processes of plastics. Global GHG emissions from well to refineries in 2015 are approximated to be 1.7 gigatons CO2e [102]. Considering the distribution of around 4% of crude oil as plastics' raw material, it is projected that the world's oil sector contributed around 68s million tons of CO_2e to the emission of plastic manufacture in 2015. New facilities for the production of natural gas has been completed or strongly suggested thus far, and there will be additional developments in the following decades. These facilities are driven not just by the need for natural gas but also by the fast expansion of the plastics industry. Thus, the influence of oil, coal, and gas extraction on GHG emissions is concerning, and this is doubtful that GHG emissions would be diminished without a considerable reduction in these large industries, which are only the first stage in plastic manufacture. Moreover, the plastics manufacturing process contributes to global warming by releasing GHGs. These emissions result from the conversion of petrochemical raw materials into usable commodities including propylene and ethylene [103]. Based on the effectiveness, control system, and service life of the product, manufacturing plants often manage GHG emissions during production. In the America, 72 plastic manufacturing units produced roughly 17 million tons of CO_2e in 2014, or 46,324 tons per day [104]. Many industrial procedures for the purpose of converting fossil fuels to plastic materials, in addition to a large number of manufacturing steps, make it significantly challenging to ascribe GHG emissions from industry to plastic manufacture. Considering the shortage of information on GHG emissions from the entire procedure of plastic production, the growing evidence indicated that plastic manufacturing is associated with GHG emissions. Plastic manufacturing is worldwide, as are GHG emissions and their effects.

Except for the direct emission of GHG, plastic debris, especially maritime plastic, may contribute to global warming in a less direct but eventually more substantial way by impacting organisms that serve as the basis of the ocean food web [105]. Ocean is considered the most significant natural pool of carbon dioxide that has a crucial function in adsorbing carbon from the atmosphere. As the capability of the ocean for carbon adsorbing is unsettled, the earth's carbon cycle will change dramatically, therefore endangering the primary necessities for the survival of humans. The particular question is whether oceanic (micro)plastic can interrupt ocean carbon sequestration. Evidence has indicated that (micro)plastics negatively impact growth and photosynthesis of phytoplankton [106]. Phytoplanktons play a tremendous role in the oceanic ecosystem. Phytoplankton is considered the basic producer of marine ecosystems, and it can use sequestrated atmospheric carbon for producing organic matter and oxygen through photosynthesis (Figure 1.9). However, reflecting and shielding sunlight by microplastics at the surface of the ocean can diminish phytoplankton's sunlight absorption and decrease the capability for photosynthesis of these creatures. Laboratory investigations indicated that microplastic exposure has detrimental impacts on phytoplankton, and the smaller the microplastics, the higher their negative impact [107].

Moreover, microplastics may damage zooplankton by having toxicity on them and affecting reproduction and development of these creatures. Zooplanktons are the primary and most significant consumers of phytoplankton. Zooplanktons have a vital role in the flow of mass, the regeneration of oceanic nutrients, and energy, the cycling of biogenic elements, genetic information through the food chain, and the decomposition of oceanic pollutants. Zooplanktons are able to degrade particulate organic carbon (POC) in the ocean via respiration; hence, they can affect the profundities of remineralization of oceanic POC and the ability of marine in adsorbing atmospheric carbon. If zooplanktons are not entangled in the processes of OCS, the sequestered carbon will return to the atmosphere and water right away. However, the prevalence of microplastics in the oceans could have a harmful impact on ocean's ability for sequestrating CO_2. Because ingesting microplastics causes satiety, scientific studies acknowledged that they may have negative impacts

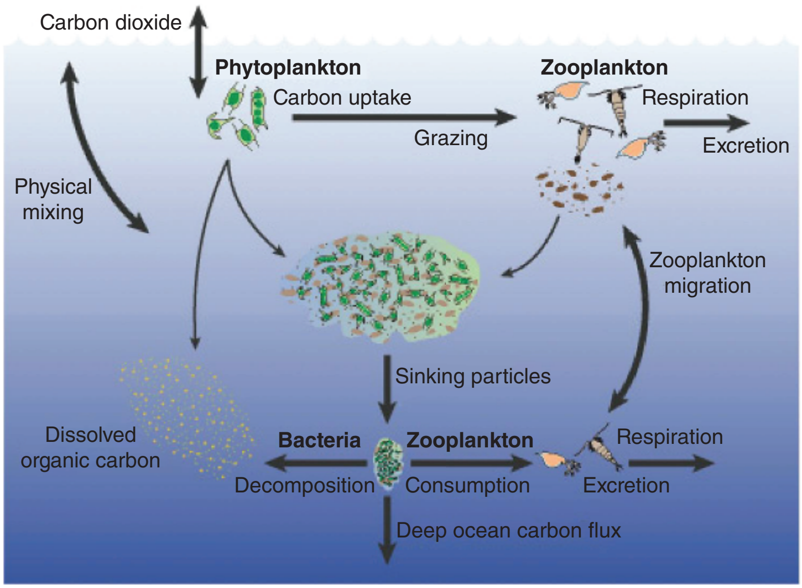

Figure 1.9 Microplastics harmful effects on the ocean carbon sequestration. Source: Gander [106]/© Taylor & Francis.

on zooplankton (copepods) and diminish their carbon consumption. After ingesting (micro)plastic, copepods consumed 40 percent less food, and over time, their eggs grew smaller and were less likely to hatch, increasing their overall death rate. Moreover, increasing zooplankton exposure to (micro)plastics over time may significantly reduce their consumption of carbon-containing material [108]. Moreover, as zooplankton antecedes phytoplankton, fecal particles transport the carbon they consume to the ocean floor. Then these particles descend gradually into the ocean's depth and deposit within the mud of the ocean floor. Cole et al. noted that fecal pellets could transport microplastics to the seabed [108]. Scientific studies have revealed that fecal particles with microplastics had much smaller comparable spherical diameters and a 1.35-fold lower descending rate [109]. Further, compared to unpolluted pellets, microplastic-polluted pellets descend more slowly and degrade more quickly, reducing the amount of carbon that settles on the ocean floor. However, the knowledge of (micro) plastics' behavior and impacts in deep ocean is still in its embryonic stages. As such, further investigations are required to comprehend the probable dimensions, scope, and main factors of the issue.

1.6 Management Strategies for Plastic Debris

Given the aforementioned, plastic pollution is a global issue. Plastic waste causes harm that is not localized to any one area; rather, it has global effects and poses global concerns. Therefore, international cooperation is necessary for countermeasures to control plastic debris. Furthermore, it is critical to recognize that the suggested strategies to deal with plastic litter must be sustainable. These ought to make a significant difference in reducing the amount of plastic in the environment, but they should not be considered exhaustive. Source reduction, remediation, and cleanup should all be priorities in any countermeasures used to manage and reduce plastic pollution. This section after that lists these measures. It should be remembered; nevertheless, that each of these strategies has its pros and cons.

1.6.1 Improving 4R Concept

Assume that public attention to the environmental and public health hazards of plastic waste is widely expanded through Big Tech companies and the mainstream media. It is to be hoped that this will result in a major decrease in the consumption of various plastic goods, such as disposable plastic. The quantity of plastic waste that enters the environment can be drastically reduced by developing recycling technique, boosting recycling-related infrastructure investment in solid waste, and creating a circular economy. Moreover, repeated use of plastic products can greatly lower the quantity of debris that is generated and that enters the ecosystem (while taking into account health considerations). Plastic debris also can be used as a source of energy (incineration, pyrolysis, and gasification), and their ingredients can be recovered to create useful products and synthetic crude. A circular economic model could address plastic leaks at all life cycle steps. The environmental leakage minimization needs consensus and adaptation of all stakeholders, for instance, discouraging littering, and designing for reuse (Figure 1.10) [110]. Most probably one key to the performance of this model for circular economics is to enhance the value

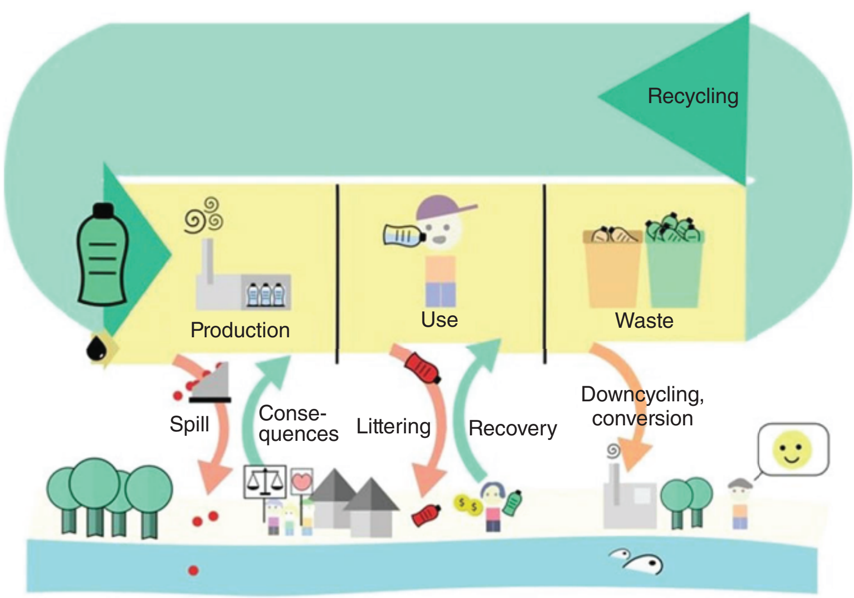

Figure 1.10 Circular economy model for plastic materials. Source: Eriksen et al. [110]/ Springer Nature.

chain of plastic materials at all stages of their functional life. The model also highlights preventive efforts when environmental concerns are taken into account. In addition, prevention is far better for the environment and more economical than some postconsumer cleanup schemes.

1.6.2 Landfills

Plastic debris dumping in landfills, therefore, seems as one of the ultimate approaches for removing almost all plastic waste from the environment, effectively establishing a linear economic model. Landfills are any sites where we discard all used plastic waste prior to burying it under the earth's surface. Many safety precautions should be taken throughout this manual disposal process to prevent further adverse effects, including groundwater pollution and soil deterioration, which can arise from substandard treatment [111]. In order to meet the aforementioned goals, landfill arrangements are designed to give a safer site for the discharge of plastic debris while also protecting aquatic life and airspace. It requires a lot of effort on the part of the community, such as excavating a deep pit or dumping at great depths and then filling this with waste and leaving it to decompose. This procedure is carried out very slowly and may take over a year [112]. Evey inorganic compound is subject to microbial degradation and breakdown in the landfill's processes. When disposed of in landfills, due to their unique biochemical characteristics, different plastic debris may require a long period of time to degrade [113]. As a result, reuse or recycling must be the first option to dispose of all plastic products properly. Landfills are a great source of energy because of the carbon dioxide and methane gas generated by microbial degradation. It helps to maintain sanitary conditions in urban areas and separates wastes into usable and potentially hazardous categories. Furthermore, managing plastic waste in this way is economical. Despite the fact that this approach can be utilized for managing plastic debris, it has significant drawbacks, such as contributing to global warming. It is ecologically damaging and contaminating the water and the soil [114].

1.6.3 Development of Cleanup Technologies

Discharging into the ocean, incineration, and burying in landfills are among the traditional practices for the disposal of plastic garbage, all of which may result in secondary pollution [115]. Therefore, a smart method for dealing with plastic debris is to create and develop the appropriate cleanup approach for plastic-contaminated places. The breakdown of organic polymers into smaller chemicals such as H_2O and CO_2 is a process known as biodegradation [116]. Microorganisms have an intrinsic capability to adapt to many environments and have the ability to degrade different chemical compounds, such as microplastics [117]. Microbes' employment for microplastic degradation will improve biodegradation [115], making it an advantageous and environmentally secure approach to promote natural biodegradability and to

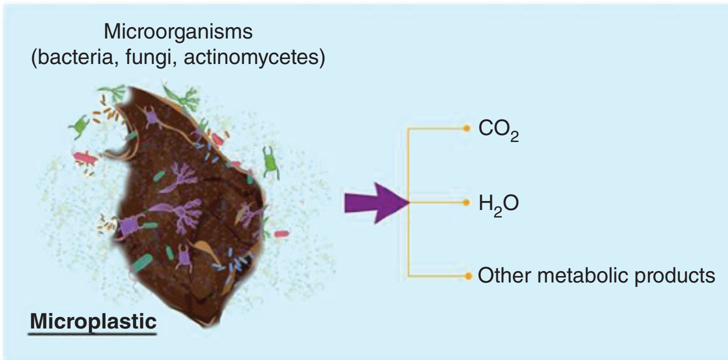

Figure 1.11 Microorganism potential for (micro)plastic degradation.

improve cleanup of the environment without generating unfavorable effects [118]. Scientific studies have noted that different kinds and mixtures of microorganisms, including bacteria, bacterial consortia, fungi, bacterial, and biofilms, can degrade various microplastics (Figure 1.11). However, few applicable microorganisms have been isolated at present, microorganisms' and microplastics' interactions have yet to be clarified, and there stays a lack of knowledge regarding microplastic biodegradation. Hence, it seems crucial to extend acquaintance by specifying how to develop further functional microorganisms and enhance their microplastic-degrading performance, as well as to elevate knowledge of how microbes metabolize and use microplastics [119].

1.7 Conclusion

Plastic products are very useful in today's world due to their unique features. Plastic production has expanded significantly. Therefore, the production of plastic waste has become a serious concern due to insufficient waste management infrastructure in most parts of the world. The chapter demonstrates the adverse consequences of plastics debris on the environment and public health as a result of exposure to harmful ingredients utilized in the production of plastic materials. People utilize plastics without completely realizing how hazardous they are. However, the majority of the literature clearly has demonstrated how hazardous plastics are to both public health and the environment. The nation's government, law-enforcing bodies, and health authorities should do more attempt to promote the manufacturing, usage, and disposal of plastics in a sustainable manner. Moreover, the chapter provided some sustainable and appropriate strategies to ameliorate the adverse impacts of plastic debris. These techniques for addressing plastic debris are not only practical economically, but they can also aid in the eradication of infectious diseases that are spread by contaminated plastic particles.

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