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Review

Contribution of plastic and microplastic to global climate change and their conjoining impacts on the environment - A review

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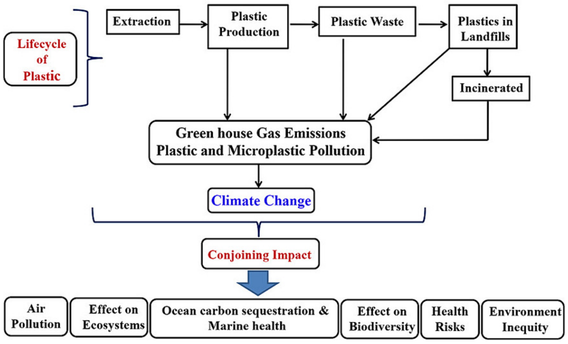
HIGHLIGHTS

- Impact of plastic pollution on the world's climate is a matter of concern.
- Emissions of GHG during plastic lifecycle contribute to global temperature rise.
- Microplastics are a major threat to ocean carbon sequestration and marine health.
- Plastic pollution and climate change affect both terrestrial and marine ecosystems.
- A sincere approach is needed to tackle the plastic and climate impact on environment.

GRAPHICAL ABSTRACT



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ABSTRACT

Plastics are fossil fuel-derived products. The emissions of greenhouse gases (GHG) during different processes involved in the lifecycle of plastic-related products are a significant threat to the environment as it contributes to global temperature rise. By 2050, a high volume of plastic production will be responsible for up to 13 % of our planet's total carbon budget. The global emissions of GHG and their persistence in the environment have depleted Earth's residual carbon resources and have generated an alarming feedback loop. Each year at least 8 million tonnes of discarded plastics are entering our oceans, creating concerns regarding plastic toxicity on marine biota as they end up in the food chain and ultimately affect human health. The unsuccessful management of plastic waste and its presence on the riverbanks, coastlines, and landscapes leads to the emission of a higher percentage of GHG in the atmosphere. The persistence of microplastics is also a significant threat to the fragile and extreme ecosystem containing diverse life forms with low genetic variation, making them vulnerable to climatic change. In this review, we have categorically discussed the contribution of plastic and plastic waste to global climate change covering the current plastic production and future trends, the types of plastics and plastic materials used globally, plastic lifecycle and GHG emission, and how microplastics become a major threat to ocean carbon sequestration and marine health. The conjoining impact of plastic pollution and climate change on the environment and human health has also been discussed in detail. In the end, we have also discussed some strategies to reduce the climate impact of plastics.

Abbreviations: GHG, Greenhouse gases; PE, polyethylene; PP, polypropylene; PVC, polyvinyl chloride; %, percent; CIEL, Centre for International Environmental Law; CAGR, compound annual growth rate; WHO, World Health Organization; LDPE, low-density polyethylene; HDPE, high-density polyethylene; PS, polystyrene; PET, polyethylene terephthalate; ARB, antibiotic-resistant bacteria; MARB, multi-antibiotic resistant bacteria; ARGs, antibiotic resistance genes; °C, degrees Celsius; HDI, Human Development Index; bio-PE, bio-based polyethylene; PHAs, polyhydroxyalkanoates; TPS, thermoplastic starch; PLA, polylactic acid; LCA, Life Cycle Assessment; DEHP, (2-Ethylhexyl) phthalate; DBP, Di-n-butyl phthalate; BBP, Benzyl-butyl phthalate.

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Contents

1. Introduction

Plastics are synthetic polymers produced by the polymerization reaction of monomers, which are mainly derived from gas and oil extraction (Okoffo et al., 2019). These polymeric materials are bestowed with interesting properties like lightweight, versatility, flexibility, strength, humidity resistance, and, most notably, economic benefit that has made them a suitable candidate for different domestic and industrial applications (Iroegbu et al., 2020). The replacement of plastics in place of glass, metal, and wood raised their global output by approximately 580 billion US dollars in 2020. According to reports, global plastic production surged from 2 to 380 megatons between 1950 and 2015 and approximately 9 % of plastic debris had been recycled, 12 % was incinerated, and about 79 % of plastic was collected in landfills (Geyer et al., 2017). It is also expected to exhibit a substantial rise over the coming decade. The most common plastic polymers are polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC), comprising 21 %, 24 %, and 19 % of the total global plastic production, respectively (Wright et al., 2013).

Due to the non-degradable nature of these polymeric materials coupled with increased consumption and low waste management standards, plastic wastes have accumulated in the ecosystem and pose a severe environmental threat across the globe (Ribeiro et al., 2019). The lower rate of recycling activity and enhanced utilization of single-use plastic products are some of the activities worsening the scenario of plastic pollution. For example, in the US, only 9.4 % of plastic is recycled due to collection costs, lack of requisite infrastructure, and poor demand by processors for recycled plastic granulation (Oudejans, 2017). On average, 60 % of plastic debris was landfilled, and only 18 % of plastic trash was recycled in the year 2015. Approximately 12 million tonnes of uncontrolled plastic debris in the environment were released annually, comprising 40 % of single-use plastic, making it a critical environmental issue (Jambeck et al., 2015). In addition, the absence of proper plastic waste management has led to >250,000 tons of plastic fragments deposition in marine bodies (Eriksen et al., 2014). The coastal countries are reported to release approximately 4.8 to 12.7 million metric tons of plastic litter into water bodies (Prata et al., 2020). It was reported that the amount of plastic fragments in marine ecosystems has risen by 7000 t (Cózar et al., 2014) and is expected to reach 270 million tonnes by the end of 2060 (Benson et al., 2022). The amount of plastic particles floating around freshwater and marine bodies remains unknown. The plastic fractions entering marine bodies depend on different topographical factors, like vegetation, climate, and particle dimensions (Lebreton and Andrady, 2019). Plastic fragments have been detected on shorelines of each continent; specifically, this problem is more prone in popular tourist destinations and densely populated areas. In this context, plastic pollution in the Mediterranean basin has been identified as a serious threat due to different plastic-related activities from the surrounding countries, making the Mediterranean Sea a plastic hotspot (Sharma et al., 2021). The rapid increase in plastic consumption will ultimately result in a rise in associated post-consumption plastic debris. By the end of 2025, it is expected that the global municipal population will generate >6 metric tonnes of plastic waste daily (Hoornweg et al., 2013). The sources of land-based plastic waste in marine bodies are inadequate waste disposal, industrial activities, construction, sewer overflows, stormwater runoff, and illegal dumping. Ocean-based plastic pollution primarily comes from nautical activities, fishing, and aquaculture (Sharma and Chatterjee, 2017). Approximately 35 % of all plastics produced worldwide are high-density plastic and can sink to the seafloor. The remaining 65 % of plastic wastes float on the surface and can travel vast distances in the ocean (PlasticsEurope, 2019). Marine plastic waste causes considerable economic damage to communities and industries, ranging between USD 8 billion to USD 2500 billion (Beaumont et al., 2019).

During and after the COVID-19 outbreak, an unprecedented requirement and consumption of plastic materials led to the release of single-use plastic products in the environment, and ever since pyramid of plastic waste in the environment has been burgeoning. It had been estimated that a massive amount of single-use plastic litter had been produced across the globe, with 1.6 million tonnes of PPE (facemasks) and 3.4 billion single-use facemasks being discarded daily during the COVID-19 period. The Asian continent produced the highest quantity of single-use plastic facemasks (1.8 billion per day), followed by Europe (445 million per day), Africa (411 million per day), Latin America (380 million per day), and North America (244 million / day) (Benson et al., 2021). This pandemic has also led to an overall surplus increase in plastic pollution, which is also associated with negative impacts on biodiversity and reduced recycling provision (Gibbons et al., 2022). The published reports on global plastic pollution during the Covid-19 time showed short and long-term environmental risks associated with toxic GHG emissions from plastic production and incineration facilities (Winton et al., 2022). Due to this sudden boom of plastic pollution and lack of proper management of these plastic wastes, a new pandemic linked to the *plastisphere* may soon be going to affect our environment and human health.

A report published by the Centre for International Environmental Law (CIEL) in 2019 concluded that the impact of plastic production on the world's climate would be very critical. By 2050, the increased plastic production will be responsible for approximately 13 % of our planet's total carbon budget, equating to 615 coal-fired power station emissions (Hamilton and Feit, 2019). The adverse effect of plastic pollution has also been expanded in all regions of the marine ecosystem, starting from shallow coastal areas to the deepest layers of the aquatic bodies sampled to date and in the most remote and sensitive locations on Earth (Napper and Thompson, 2020). Over the last two decades, marine pollution by plastic debris has been increasing and significantly contributing to global climate change. The impact of climate change is already in place in the form of a sea-level rise, ocean acidification, and extreme weather conditions, leading to socio-economic and ecological harm (Ford et al., 2022). Therefore, intensive research on the impact of plastic pollution on climate change is the need of the hour so that decision-making agencies can frame mitigation policies to tackle this menace. In this review, we discuss how increasing plastic production (and microplastic thereafter) and their indiscriminate use lead to global climate change and their conjoining impact on the environment. One of the main objectives of this review is to show the impact of plastic pollution on climate change and how they are interrelated. Here we have categorically discussed how plastic contributes to the emissions of greenhouse gases from its generation to end of life including the impact of microplastics. The vulnerable effects of plastic-associated climate change on terrestrial and marine ecosystems, the environment, and human health have also been discussed. This review also covers the different strategies to reduce the climate impact of plastics and proposes a few measures. This information will help future researchers to critically analyze the interconnected problems associated with plastic pollution and climate change and find some realistic mitigation strategies.

2. Methodology

A Google-based search showed that the connection between plastic pollution and climate change is being exploited by only 0.4 % of the articles which examined both stressors simultaneously. For this review, a systematic search approach has been followed. Most information on plastic pollution and its associated climate change has been collected from various internet resources, including press releases, news media, reports published by non-profit and advocacy organizations, and other peer-reviewed literature. Search keywords were either closely related to plastic pollution, such as plastic debris, microplastics, plastic types, COVID impact, effect on marine health, carbon sequestration, human health, or policies (to curb plastic pollution along with different policies laid down by the government of different countries for manufacturing and consumption of plastic associated products) and climate impact. Moreover, each search was further expanded with combinations of different words, including “plastic and climate change,” “pollution associated climate change,” “effect of plastic pollution on terrestrial ecosystems,” “effect of plastic pollution on marine ecosystems,” and “climate change impact on ecosystems.” We performed Google, PubMed, and Web of Science searches using all these mentioned search terms and stopped exploring further when the searches were unrelated or duplicative. The literature review identified approximately 600 scholarly journal articles on plastic pollution, its associated climatic impacts, and the individual impacts of plastic and climate change on the environment. We then analyzed these search results and extracted the relevant information for review writing.

3. Commercial plastic production- current scenario and future trends

Commercial plastic production started in the 1950s, and after that, it showed an exponential rise in the production pattern to attain the global plastic market size, which was valued at USD 593.00 billion in 2021. It is expected to increase further at a compound annual growth rate (CAGR) of 3.7 % from 2021 to 2030. Over recent years, plastic products have been a significant demand as a suitable replacement contender for various metals and alloys in the industrial sector. This growth is attributed to various factors such as production process, feedstock availability, increased end-user demands regarding product specification and versatility, and other socio-political factors (Plastic Market Report, 2021).

The outbreak of COVID-19 in 2020 is also fuelling the plastic demand in the medical and pharmaceutical industries. The increasing number of positive COVID-19 cases worldwide is raising the demand for plastic polymers used in testing equipment, ventilators, medical bags, gloves, masks, PPE kits, surgical trays, and syringes (Silva et al., 2021). According to the World Health Organization (WHO), 76 million disposable gloves and 89 million medical masks were required per month for the battle against the virus. Owing to these statistics, in March 2020, the WHO urged plastic manufacturing companies to increase the manufacture of plastic polymers by 40 % (Higgins-Dunn and Kopecki, 2020). In April 2020, Exxon Mobil Corporation increased the production of specialized polypropylene by 1000 tons per month to cope with the demand for medical masks and kits. This surge forces manufacturers to make additional polypropylene for 200 million medical masks and 20 million kits (Varma, 2020). The International Energy Agency (IEA) report also stated that plastic production showed a sudden increase since 1950 and would exponentially grow in the coming years, reaching approximately 540 million metric tonnes by 2040 (Fig. 1) (Bassetti, 2020).

On the commercial level, the plastic packaging industry is also a significant contributor in recent times, and this market is expected to attain a CAGR (Compound Annual Growth Rate) of approximately 4.2 % from 2021 to 2026. The COVID-19 pandemic offered a boom to the single-use plastic packaging sector as the demand for essential products (healthy food, nutritional drinks, and essential groceries) increased exponentially. The high demand for single-use plastic packaging on a global scale promoted plastic packaging companies to expand their facilities with government support. The single-use packaging market was USD 36.76 billion in 2021 and this is expected to increase to USD 50.98 billion by 2027. The single-use plastic packaging is the prime end-user segment accounting for 40 % of total plastic consumption across the globe. It is estimated that approximately 2 million plastic bags and 1 million plastic bottles are dispensed in the world every minute, and this figure is supposed to be half a trillion by the end of 2022 (Global Plastic Packaging Market, 2022–2027).

It is unfortunate that the plastic economy has adopted 90 % of products for one-time use and thus putting intolerable pressures on the global environment. Approximately 80 % of plastic debris comprises landfills resulting in up to 2.4 million tonnes of polymer waste entering marine bodies yearly (Lebreton et al., 2017). The durability of plastic is now its curse as plastic residues tend to sustain in our environment for centuries, and even when degraded, it transforms into microplastics and nanoplastics. These microplastics and nanoplastics ultimately enter the food chain and create severe health issues for humans and other species in the environment (Sharma and Chatterjee, 2017). Therefore to maintain a sustainable ecosystem a tangible solution is required immediately to this plastic waste problem.

4. Types of plastics and plastic materials used globally

Plastic-related products are made up of plastic polymers in which additives are mixed to impart certain specifications for the product (Wiesinger et al., 2021). To improve the efficiency of plastics, the resins are generally mixed with additives. The additives are, (i) inorganic fillers (such as carbon or silica) used to strengthen the plastic, (ii) thermal/heat stabilizers (lead) for the processing of plastic at high temperatures, (iii) plasticizers (e.g. phthalates, terephthalates) to impart flexibility, (iv) flame retardants (Chlorine and bromine) to retard ignition and burning and (v) UV stabilizers to avoid photo-degradation of plastic whenever exposed to direct sunlight (Murphy, 2001). These additives are a real threat to human and animal health due to their genotoxicity (many of them are listed in the Stockholm Convention on Persistent Organic Pollutants (POPs) (Secretary-general UN, 2009).

The plastic demand in the global market is mainly dominated by thermoplastics which include polypropylene (PP) (21 %), low-density polyethylene (LDPE) (18 %), high-density polyethylene (HDPE) (15 %), polyvinyl chloride (PVC) (17 %), polystyrene (PS) (8 %) and polyethylene terephthalate (PET) (7 %) (Hahladakis et al., 2018). Approximately 30 % of the polyethylene (PE) film is produced for global market consumption, specifically

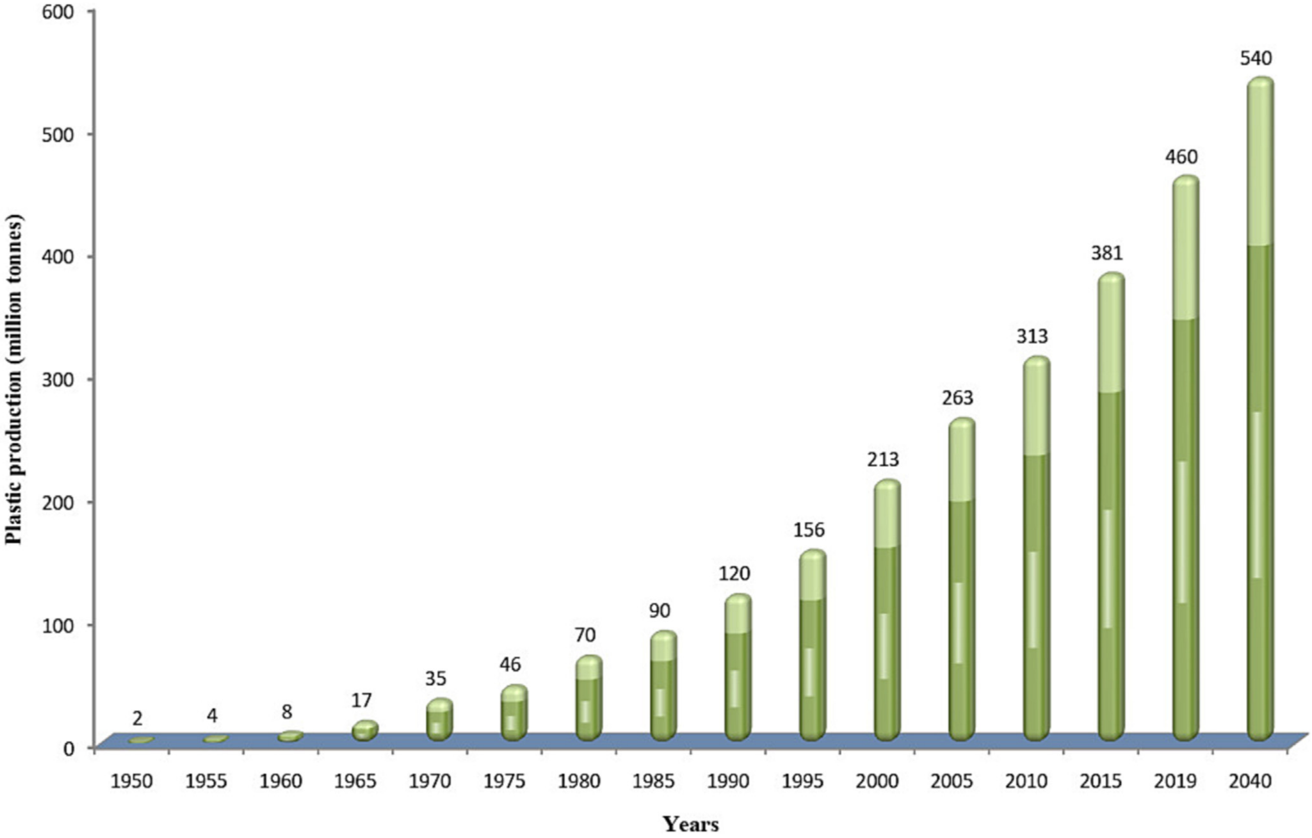

Fig. 1. Profile of global annual plastic production.

on Western European, North American, and Asian continents. Currently, half of 35 million tonnes of PE resins are manufactured internationally for plastic films, followed by injection-molded and blow-molded plastic products (13–14 %). The commercial applicability of PE plastic films includes carrier bags, freezer bags, and cling sheets. These plastic films are also utilized for agricultural practices such as field liners and irrigation pipes. The specific applications of PE in blow-molded containers with volume capacity ranging from milliliters bottles (200–500 cm^3) and containers (0.5–4 l) to hundreds of liters barrels. PP is also a cost-effective and valuable polymer that can be utilized in different forms (viz., blow-molded, injection-molded, and film extrusion into various industrial essential products). Common examples of PP include barrier film flexible pouches, stackable storage crates, caps for containers, thin-walled food containers, blow-molded bottles, and many others. The PP is also used for construction purposes such as window/door frames, water or sewage pipes, and geo-membranes (Andrady and Neal, 2009).

The commodity plastics PVC differ by having additional chlorine (around 57 % by weight) in addition to carbon and hydrogen. Generally, PVC is produced in the form of a white powder, blended with other components for the required formulation of different products. According to a report published in Plastics Europe, the annual demand for PVC across the world is around 35 million tonnes, with approximately 1 % per annum predicted growth. The demand for PVC in the Asian market (mainly in China) is approximately 40 % of the total global demand. The chlorine content in PVC makes it non-combustible and thus has a major application in the construction market, including piping, window shutters, and upholstery (Andrady and Neal, 2009). The PS is a high-quality plastic polymer available in two grades: a general grade PS and a high-impact grade PS modified with polybutadiene. In 1954, another grade, expanded PS was launched by the Dow Chemical Company, which is nowadays utilized as a brilliant insulating ingredient used in the construction of buildings and also for moldable packaging material. Expanded PS is used for manufacturing consumer goods (cups and trays) and industrial packaging of high-value goods such as electronic commodities and lighting in transport vehicles. The other high-grade plastic polymer that revolutionized the commercial market was PET, which was discovered in 1941 (Coniglio et al., 2020). PET was licensed to DuPont and ICI chemists, who further developed PET fibers. PET is of enormous economic importance with a balance of properties such as transparency, lightweight, glossiness, and a barrier to environmental factors such as gas permeation. European countries have fully substituted glass with PET for all the essential applications requiring oxygen barrier and UV resistance. Due to its versatile use and popularity among users, the demand for PET has jumped to nearly 14.5 million tonnes per annum and is increasing at a rate of 8 % per year (Plastics Europe, 2008).

4.1. Differentiation of plastic based on decomposition

Commercial Plastics are nonbiodegradable, and after being discarded into the environment, they undergo many degradation processes by different routes, such as photo-degradation, thermal degradation, UV radiations, and hydrolysis, and ultimately lose their structural rigidity. This plastic degradation results in the formation of microscopic-sized microplastics having dimensions in the range between a few micrometers to 500 μm. These microplastics are further degraded into nano plastics of size <100 nm (Sharma and Chatterjee, 2017). However, the duration of plastic decomposition depends on various factors such as plastic type, composition, and landfill condition. Polyethylene terephthalate (PET) is the most recycled plastic and takes approximately 450 years to disintegrate. The high-density polyethylene (HDPE) has a tougher chemical structure than low-density polyethylene (LDPE). It takes nearly 450 years to degrade through landfill, while LDPE decomposes in between 2 to 20 years. Polypropylene (PP) is complex and resistant to acids and bases. It can be biodegraded by microbial action and takes 200–450 years for degradation through landfill. In contrast, polystyrene (PS) can only be broken by the action of methanogenic consortia and takes nearly 500 to 1 million years to get degraded (Maesindo paper packaging company, 2020).

5. Contribution of plastic to global climate change

5.1. Lifecycle of plastic (plastic production) and greenhouse gas emission

The emissions of greenhouse gases (GHG) during different processes involved in the lifecycle of plastic-related products are a significant threat to the environment as it contributes to global temperature rise. Plastic building blocks are comprised of fossil fuels (crude oil, gas, and coal), and greenhouse gases are emitted at every stage of the plastic lifecycle. Following are the process of greenhouse gas emissions during the different stages of the plastic lifecycle (Fig. 2).

5.1.1. Extraction and transport of fossil fuel

During plastic raw material production, different processes involved in extracting and transporting fossil fuels are the main contributors to greenhouse gas emissions. Gas and oil are extracted from the Earth's core by drilling down into the deepest layer of the Earth. Pressurized liquid (fracking liquid) is used to create cracks in the deeply layered rocks to release natural gas, a process known as fracking (Alhazmi et al., 2021). The emitted gas is then transported through pipelines, trucks, and trains. This extraction and transport process is a highly carbon-intensive process that includes (i) direct emissions of methane and carbon dioxide, (ii) emissions of carbon dioxide from energy and fuel consumption during the drilling process, and (iii) emissions of carbon dioxide during transport through pipelines. In a report published by the CIEL, it was estimated that in the US, during the extraction and transportation process (fossil fuels for plastic production), approximately 12.5–13.5 million metric tons of carbon dioxide is emitted per year (Hamilton and Feit, 2019). The extraction process is associated with land disturbance contributing to greenhouse gas emissions. In the US, approximately 19.2 million acres of land have been cleared for gas and oil production, which resulted in the release of 1.686 billion metric tons of carbon dioxide into the atmosphere (Bauman, 2019).

5.1.2. Refining and manufacturing

The refining process converts raw crude oil into petroleum products. These products are then converted to yield valuable chemicals (such as ‘monomers’), which are the fundamental building units of polymers. In this refining process, the crude oil is first heated in a furnace and then transferred to the distillation process, separating it into lighter elements called ‘fractions.’ These fractions are a mixture of hydrocarbon chains which ultimately converted into final products. One significant fraction called naphtha is formed during this process, a crucial compound for large-scale plastic production (Baheti, 2022, Wang et al., 2021a,b). Both refining and manufacturing are highly energy-intensive processes as they require high heat and emit significant carbon dioxide into the environment (Royer et al., 2018). In 2015, during the manufacturing of PE plastics, 184.3–213 million metric tons of carbon dioxide emissions were reported. With this pace of plastic production, carbon dioxide emissions are predicted to jump to 34 % by 2030 (Bienkowski, 2019).

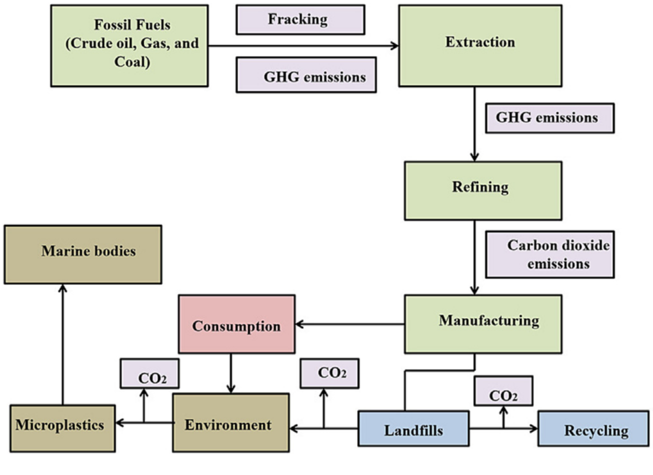

Fig. 2. Overview of the lifecycle of plastic and GHG emission.

The rapid ongoing expansion of the petrochemical and plastic sector has raised serious climate issues. In Pennsylvania, a new natural gas processing plant was constructed to supply constituents required for the plastic manufacturing industry. It was observed that this plastic processing plant could emit approximately 2.25 million tons of harmful greenhouse gases per year. In Texas, an ethylene plant constructed by ExxonMobil's Baytown refinery will release up to 1.4 million tons of GHG yearly (Hamilton and Feit, 2019). Thus by the end of the century, this sudden expansion of the plastic industry will lead to the consumption of >125 gigatons of carbon dioxide. The annual global emissions of GHG and their accumulation in the environment will continue in the coming decades, and this process will consume approximately 10 % of the Earth's residual carbon resources.

5.2. Plastic waste and global climate change

Plastic leakage into marine habitats has shown a sudden exponential growth in recent years and by 2040, per year nearly 23–37 million metric tons of plastic waste will be noticed in marine habitats. The seriousness of this issue of plastic in water bodies is depicted by the fact that the persistence of plastic has been detected in the deepest layer (appropriately eleven kilometers below) of the sea in the Mariana Trench (Morelle, 2019). This plastic persistence in oceans will release harmful greenhouse gases, create an alarming feedback loop, and disturb the carbon sink cycle.

The unsuccessful management of this plastic waste across the world has a direct and indirect impact on the global climate scenario. The reason is that the plastic litter that does not end up in the recycling plants is transformed into microplastics and enters our rivers and oceans (Sharma and Chatterjee, 2017). It will pose a severe threat to marine biota and the climate, as plastic decomposition is associated with the release of greenhouse gases (carbon dioxide, methane, and ethylene). The research on microplastics suggested that the presence of microplastics in a marine ecosystem affects the ability of marine biota to absorb carbon dioxide and release oxygen, which could accelerate the loss of oceanic oxygen (Edmond, 2022). Waste management is not easy as only one-fourth of the total plastic produced is recycled due to the lack of a functional waste management system. The authorities and industries are innovating different methods for plastic waste management, but unfortunately, some of these methods are also contributed to GHG emissions. Incineration is one method that releases plenty of GHG (mainly CO_2) along with highly toxic chemicals. This waste incineration, also known as Waste-to-Energy, is the key source of GHG emissions, although electricity generation is also associated with the process. It is proved in a study that the incineration of one metric ton of plastic waste resulted in almost one ton of CO_2 emissions from the incineration process (Verma et al., 2016). The CIEL report stated that in 2015, approximately 5.9 million metric tons of carbon dioxide were emitted from plastic waste incineration in the US. In 2019, the plastic production and incineration process produced approximately 850 million metric tons of greenhouse gases, equal to the total emissions from 189 five-hundred-megawatt coal power plants. According to World Energy Council, with this rise in plastics production and plastic waste incineration, CO_2 and other toxic gas emissions will rise to 49 million metric tons by 2030 and 91 million metric tons by 2050. The plastic industry was estimated to contribute approximately 10 % of global warming potential among other contributing groups (Hamilton and Feit, 2019).

It is important to note that carbon emissions from plastic waste are not restricted to production stages only. The degradation of long carbon chains of plastic products naturally emits toxic greenhouse gases, mainly methane and ethylene, which have a high warming effect. The alternative to this problem is to enhance the production of biodegradable plastic materials so that environment can avoid the deleterious effect of non-bio compostable plastics (Moshood et al., 2022). The non-biodegradable plastic products are generally fossil-based polymers that exploit fossil reserves as their feedstock, whereas, the bio-degradable polymers or bioplastics use biological goods as their feedstock. The simple structural design of biodegradable plastics can be easily assimilated by natural microorganisms, yielding an end product that does not pose any risk to the environment. Both aerobic and anaerobic organisms can degrade these plastics into water, carbon dioxide, methane, and edible compost. These biodegradable plastics have similar properties to conventional ones, and in addition, they are eco-friendly and pose minimum carbon footprints.

For the optimum quantification of the environmental impacts of biodegradable plastic products in the production and utilization stages, the Life Cycle Assessment (LCA) of these bioplastics is of significant relevance (Razza and Cerutti, 2017). Reports suggested that when LCA analysis was conducted on different biodegradable plastic products, the environmental impacts were found less compared to conventional plastics. Research should be focussed on the analysis of biodegradable plastics for economic profit, environmental protection, viability, and social accountability. Government should also regulate some provisions for the commercialization of the biodegradable plastics market on a global level.

5.3. Impacts of plastic pollution on the marine, terrestrial and natural ecosystems

The impacts of plastic pollution on the marine ecosystem have been an area of interest in recent times (Derraik, 2002; Thushari and Senevirathna, 2020). A study conducted by Sarah-Jeanne Royer at the Scripps Institution of Oceanography demonstrated that plastic debris on riverbanks, coastlines, and landscapes emits a higher percentage (with a higher rate) of greenhouse gases (Royer, 2018). The plastic at the ocean's surface continuously releases toxic gases such as methane, and the rate of emissions increases as plastic degrades further to microplastics. Currently, marine species and ecosystems are very much vulnerable to plastic pollution and its associated climate change (Stubbins et al., 2021). It can be understood by the example of marine turtles, which are markedly susceptible to the harmful effects of marine plastic pollution and its related climate alteration (Patrício et al., 2021). Due to global warming, some turtle hatcheries across the globe are showing distorted female sex ratios, which further threaten their populations (Chatting et al., 2021; de Marcovaldi et al., 2016). In a study, it was demonstrated that Green turtles *Chelonia mydas* (green turtles) from warmer beaches located on the northern Great Barrier Reef have biased sex ratios (99.1 % juvenile, 99.8 % sub-adult, and 86.8 % of female adult-sized turtles) (Jensen et al., 2018). Microplastics too have a significant role in altering the temperature conditions of the marine ecosystem. An experimental study revealed that marine turtles are generally more susceptible to the hazardous effects of plastic and its components either through direct ingestion or entanglement, causing internal injury, intestinal blockage, and death (Nelms et al., 2016; Duncan et al., 2017).

Marine plastic pollution and its associated climate change contribute to global warming and higher oceanic temperature. The impact of this warming is very significant on coral reefs leading to coral bleaching (Hughes et al., 2018), causing a high mass mortality rate of coral species, and leading to the extinction of certain species (Hughes et al., 2017; Bento et al., 2016). It is important to note that corals provide habitats and shelter to vast marine biota, help in nutrient cycling, and supply nitrogen and other vital nutrients to diverse forms of marine life (Baumann et al., 2019; Ortiz et al., 2018). Multiple research studies demonstrated that ingesting plastic fragments can negatively affect gamete fertilization (Berry et al., 2019) and coral health, leading to poor photosynthetic performance and retarded growth (Lamb et al., 2018; Reichert et al., 2019).

Ecosystems are continuously and rapidly changing in response to different environmental conditions/events such as climate change, temperature changes, water balance, atmospheric carbon dioxide concentration, and the magnitude of other extreme events. They are susceptible to climate change due to complex interactions among different organisms. Climate change due to plastic pollution brings out drastic alterations in natural ecosystems threatening biodiversity and posing negative impacts on food production at a global scale. Soil microbial communities play a vital role in regulating the biogeochemical cycle. The plastic pollution associated with climate change ultimately leads to terrestrial biodiversity loss and thus affects the carbon storage of the ecosystem (Malhi et al., 2020). In terrestrial ecosystems, microplastics hinder carbon sequestration that hampers the regulation of the carbon cycle in the soil environment. Microplastics reduce N_2O emissions during nitrogen fertilization in the soil and negatively influence other nutrient cycles, such as nitrogen and phosphorous, followed by oxidative stress. The microplastic also interacts with soil fauna by inducing alterations in their biophysical environment and damaging their fitness and functioning. It was studied that earthworms and springtails help transfer the microplastics within the soil system in both vertical and horizontal directions and display deleterious effects in their functioning (de Souza Machado et al., 2018). Thus the overall soil productivity has been drastically impacted due to the imbalance of the nutrients cycle leading to a poor yield of crops and a significant food crisis at global levels (Kumar et al., 2021). In terrestrial ecosystems, the plastic composition and their association with various human activities might significantly impact the ecosystem's functioning. In a wastewater treatment plant, the surfaces of microplastic are generally loaded with pathogenic microorganisms. The sludge treatment plants do not retain these minute-sized plastic particles; they enter freshwater routes and disperse pathogenic microbes within systems. The effects of these microplastics on terrestrial or land-based ecosystems are still unexplored and are thus a thrust area for future research.

5.4. Microplastics as a major threat to ocean carbon sequestration and marine health

The overflow of plastic debris in water bodies now appears as a global problem that includes climate change, global warming, ocean acidification, and loss of marine biodiversity (Fig. 3). After landing in the water bodies, these plastics get fragmented and form microplastics. Other types of microplastics manufactured for specific use also contribute largely to water pollution. The hydrophobic surface of plastic fragments in aquatic habitats offers attachment links to different microorganisms (Lechner et al., 2014), which in turn accelerates the formation rate of biofilms. These tiny plastic fragments then become the vector for harmful microorganisms (Zhang et al., 2020). Ultimately, these adhered pathogenic microorganisms are transferred to aquatic ecosystems, spreading microbial infections to the marine system. In a study, a range of microbial communities was discovered on the surface of different polymer fragments such as PP and PE (Zettler et al., 2013). The additives such as nonylphenol and brominated flame retardants and microplastic-associated intermediates such as oxygenated compounds and oligomers, which are released during the weathering processes of microplastics, have an acute effect (such as acute toxicity and high mortality rate) on marine animals (e.g., lugworms, mussels fish, and others) (Jang et al., 2016; Wardrop et al., 2016; Wathsala et al., 2018). Different types of antibiotics such as sulfonamide, tetracycline quinolone, chloramphenicol, and β-lactamase, which are used in agriculture, are also reported to adhere to the microplastic's surface. It may encourage the development and enrichment of different antibiotic-resistant bacteria (ARB), multi-antibiotic-resistant bacteria (MARB), and superbugs and also endorse the prevalence of antibiotic-resistance genes (ARGs) (Lu et al., 2019; Wang et al., 2018). It is a serious concern at this time of the COVID-19 pandemic, as the production of plastic gear is not only at an all-time high, but management is also impoverished. Therefore, once these pathogenic strains are omnipresent in the water bodies, it would be challenging to control the spread of the disease and manage the health of marine life (Boyle, 2020).

Apart from deteriorating marine health, this biofilm coating on microplastic surfaces dramatically changes the viscosity and buoyancy properties of microplastics in water. For this reason, the hydrophobicity and floatation kinetics of microplastics decreases drastically, leading to the sinking of microplastics to the ocean's depth. This sinking ability of these tiny fragments negatively affects the distribution of carbon organic matter in the depth of water bodies, ultimately affecting the ocean's carbon stock (Kaiser et al., 2017).

The omnipresent nature of these microplastics in the oceans and other aquatic ecosystems has adverse effects on the developmental and

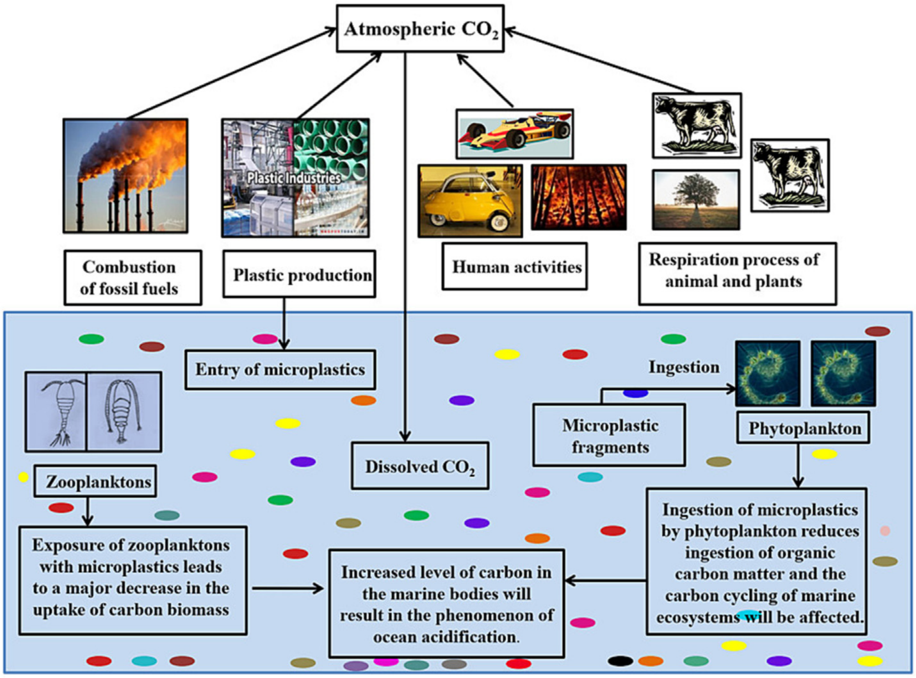

Fig. 3. Effect of plastic production and corresponding CO_2 emission on the marine ecosystem.

reproduction pattern of marine organisms and thus altering the distribution process of gas exchange and ocean carbon sequestration. Oceans are one of the biggest natural sinks of carbon dioxide and play an integral role in mitigating atmospheric carbon dioxide levels. Therefore, if the carbon dioxide sequestration in marine bodies is disturbed, a negative impact on the global carbon cycle and human health will be observed (Shen et al., 2020). Due to the change in the marine climate, ocean currents may shift the intervals, and the sea level will rise, resulting in more plastic litter on the seashores and sea (Stoett, 2016).

It is well known that phytoplanktons are involved in fixing carbon dioxide by using water and sunlight to form oxygen and other organic matter, which marine biota can consume as food. So, when these phytoplanktons are ingesting these plastic fragments, there is less ingestion of organic carbon matter, and the carbon cycling of marine ecosystems is affected. This increased level of carbon in the marine bodies is then resulting in ocean acidification. Research showed that the rate of photosynthesis by marine phytoplankton (*Dunaliella tertiolecta*) after ingesting microplastics (250 mg/l) has been reduced by approximately 45 % (Sjollema et al., 2016). Ingestion of nano plastics (1.6–40 mg/ml) by green algal species viz. *Scenedesmus* and *Chlorella* could delete the chlorophyll A content in algal species and enhance the formation of active oxygen in the cells (Bhattacharya et al., 2010). Few marine biotas such as *Chaetoceros* sp. and *Rhodopsis salina* can secrete gelatinous substances to form an algal mass which then polymerizes with the microplastics present in the marine bodies and changes the density and distribution pattern of this algal biomass (Underwood et al., 2004).

Zooplanktons also play a vital role in the marine ecosystem as these organisms help to flow mass and energy through the food chain. They are the crucial degraders of various aquatic pollutants and sometimes act as bioindicators. Zooplanktons regulate appropriate atmospheric CO_2 concentration in the water bodies by degrading aquatic particulate organic carbon (POC) through respiration and thus help maintain the climate of the marine ecosystem. However, the presence and ingestion of microplastics in oceans have adverse effects on this zooplankton leading to a reduction in carbon consumption (Cole et al., 2015). Exposure to zooplankton with microplastics also leads to a significant decrease in the uptake of carbon biomass by these planktons (Cole et al., 2016). Therefore, the persistent occurrence of these toxic plastic fragments in aquatic bodies harms the marine biota and hampers the ocean carbon sequestration process as the carbon cycle pattern gets disturbed.

Further investigations showed that these microplastics are also deposited into biodiversity hotspots of the aquatic ecosystem, thus raising the chance of ingestion by different marine biota (Chatterjee and Sharma, 2019). In the marine ecosystem, smaller microplastics are more susceptible to ingestion by marine organisms and can cause inflammation of the intestinal cavity (Liu et al., 2020). After microplastic ingestion, these marine organisms lose their appetite and change their behavior, apart from facing oxidative stress and infertility problems (Okoffo et al., 2019). A study suggested that the presence of microplastics in water bodies disrupted the ability of hermit crabs to choose shells. These crustaceans are involved in swapping their shells in search of better and bigger ones. The exposure of hermit crabs to microplastics disturbs this swapping behavior proving that marine plastic pollution harms marine biota with concerning intensity. In a study, 29 female hermit crabs were placed in a chamber containing seawater and PE microbeads (4 mm size) at a similar concentration level found in the environment. In another chamber, another set of 35 female hermit crabs was placed without PE microbeads. After incubation for 5 days, each female crab was removed from its shell and exposed to a new shell with half the perfect weight required for each female crab. The crabs in the new shell were nurtured for two hours and were then placed into a deep seawater dish. In the seawater dish, crabs were offered a new set of shells with the ideal weight of the crab. It was observed that female hermit crabs not exposed to the microplastics could explore the perfect-sized shells, whereas those exposed to polyethylene beads took longer to explore perfect-sized shells. This study indicated that contact with microplastics could affect the behavioral pattern of hermit crabs (Davis, 2020).

6. Conjoining impact of plastic pollution and climate change on the environment and human health

The global wave of plastic waste and its associated pollution is spreading in marine and terrestrial ecosystems, thus affecting the environment and human health (Fig. 4). Polar Regions are usually considered pristine surroundings with a sensitive ecosystem (Vethaak and Leslie, 2016). Climate change has adverse consequences on these extreme habitats, including changes in the season's pattern (length of the seasons), glacial

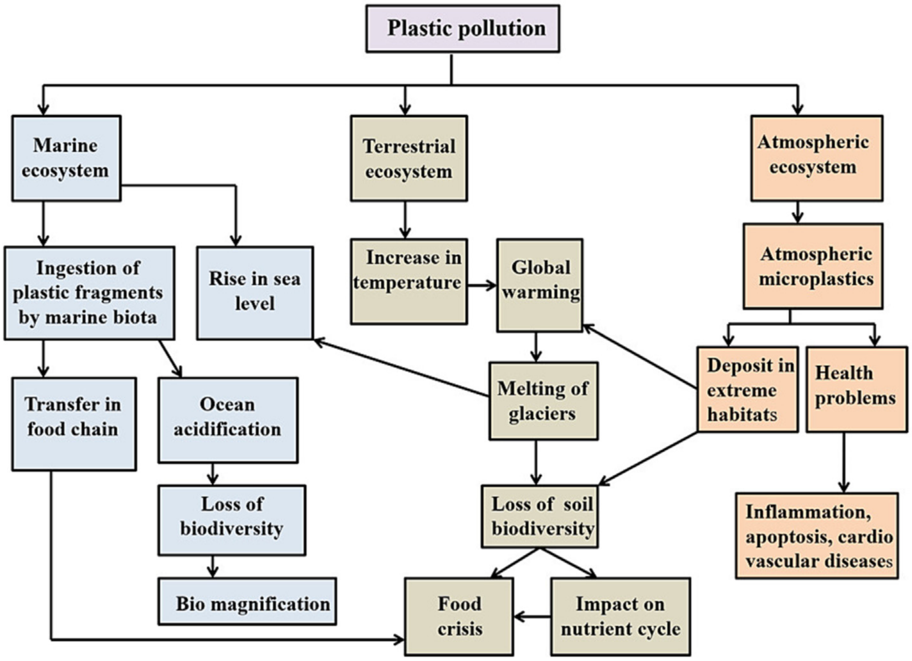

Fig. 4. Plastic pollution and its associated climate change and their combined effects on the ecosystem.

retreat, and rising sea levels. All these changes impact biodiversity at the species and ecosystem level in terms of population distribution, phenology, composition & function. Nowadays, a significant level of microplastics accumulates in sea ice and sediments, which are consumed by sea birds and other animals living in this region (Amélineau et al., 2016; Munari et al., 2017). Apart from that, microplastics also reduce the surface albedo of snow and thus accelerate melting, worsening the ecosystem's health (Evangeliou et al., 2020). The satellite images of Eagle Island revealed that the ice-covered areas are now converted to the blotch of open land and ice melt-water ponds. The visual pictures of this satellite depicted a record temperature rise in this area that has swept across the Antarctic continent. There are reports by NASA that proves that the Antarctic continent is one of the main hotspots of the Earth that is warming at the fastest pace, with standard temperatures increased to almost 3 °C in the last decade (Comiso, 2007; Shuman and Comiso, 2002). The weather stations near the northern tip of the Antarctic Peninsula and neighboring islands have recorded the highest temperatures, confirming the reports (Stone, 2020).

The presence of microplastics in these extreme areas can be attributed to various factors such as the shape, size, and length of atmospheric suspended plastic fragments, wind flow, local turbulence, wind direction, precipitation rate, and sedimentation rate (Enyoh et al., 2019). The mechanism could be predicted as snowflakes can capture these tiny plastic particles from the atmosphere during snowfall. Snow samples from Greenland and Svalbard were reported to contain approximately 1760 microplastic particles per liter (Carrington, 2019). A high count of microplastics (24,600 per liter) was also discovered in the samples of European glaciers. The persistence of these tiny microplastics is a major threat to this fragile and extreme ecosystem containing diverse life forms with low genetic variation, making them vulnerable to climatic change (Rowlands et al., 2021).

This impact of climate change on species can ripple throughout the food chain and affect organisms of a higher tropic level. For instance, in the Arctic, the decline in the sea ice leads to a reduction in the abundance of ice algae which act as nutrient-rich sockets in icy conditions. These ice algae are a food source for zooplankton, which are further consumed by Arctic cod. The Arctic cod is an essential food source for various marine organisms such as seals, and larger marine mammals like polar bears further eat seals. Thus the reduction in the first tropic level (ice algae) of the Arctic region is contributing to the reduction of the population of higher tropic levels (polar bears) (Melillo et al., 2014).

The persistence of plastic in the environment has formed an artificial ecosystem called *plastisphere*. Plastic fragments such as microplastics and nanoplastics are considered global pollutants due to their omnipresence in ecosystems and also due to their ability to interrelate with biological structures. In the terrestrial system, the soil ecosystem plays a crucial role in the maintenance of nutrient cycles and forms the platform for food and feed production. Soil ecosystems receive huge loads of plastic debris from different sources such as soil compost, effluent irrigation, plastic mulching, and biosolids (Ziajahromi et al., 2020). This alters the basic soil parameters and causes N_2O and CO_2 emissions which reduces the fertility of the soil. The plastic fragments cause a dynamic shift in the soil temperature conditions and alter soil decomposition rates, which could have negative impacts on soil ecosystem services (Kumar et al., 2021). This alteration of physicochemical parameters of soil has a significant impact on the forested land which can lead to soil erosion and forest fire, causing loss of biodiversity. Soil temperature and other physicochemical parameters play an important role in the maintenance of fauna (micro and macro) in the soil ecosystem. Temperature conditions of soil play a significant role in egg hatching and also in the sex determination of hatchlings. The persistence of plastic in the soil ecosystem has a very strong impact on the population profile and sustenance of microbial faunas (Wang et al., 2021a,b).

The plastic particles also serve as a vector for toxic chemicals and microorganisms and thus can make an entry into any ecosystem and can cause a change in biodiversity and other ecological behaviors (de Souza Machado et al., 2018). In marine ecosystems, the persistence of microplastics has an ultimate threat to marine biota and substantially increased levels of microplastics and nanoplastics have been reported in pelagic species. Research studies have demonstrated that pelagic species have elevated levels of plastic fragments in their intestine and open-ocean pelagic species are more susceptible to plastic consumption than the benthic species (Pereira et al., 2020). Due to climate change, the evolution of plasticity will significantly contribute to various phenotypic changes in aquatic invertebrates in addition to genetic changes. Thus, photoperiodic changes are omnipresent and lead to phonological alterations besides thermal adjustments (Stoks et al., 2014).

In the atmosphere, the presence of plastic fragments leads to the hindrance and lowering of the pollination rate. These microplastics generally mimic the pollens in size and hinder the pollen grains, thus the pollination gets hampered (Zang et al., 2020). The tropical region is most diverse with a high number of endemic plant species and the persistence of these plastic fragments in the tropics poses a threat to the endemic and rare plant diversity (Hu et al., 2019). This will also lead to a significant decline in endemic species with limited viable seed banks. These atmospheric microplastics due to their toxicity lead to serious health concerns such as ulcers, nasal and olfactory infections, and lung congestion. In the long run (if not already) this will result in a burden on the healthcare system infrastructure and will directly lower the Human Development Index (HDI) (Kumar et al., 2021).

There is emerging concern about plastic toxicity on marine animals and human health as they end up in the food chain. Microplastic particles have now been detected in the meat, milk, and blood of livestock animals. The highest amount of microplastic fragments is found in the human consumption items generated from the seas and rivers (such as seafood, salt, and fish). Across the globe, India is in third place for salt production. In Tuticorin, Tamil Nadu, India, both borewells and seawater are often used for salt production. A study performed on the salt samples of Tuticorin found that humans generally consume 216 microplastic particles per year per 5 kg of sea salt consumption and 48 microplastic particles per year per 5 kg of bore-well salt consumption (Sathish et al., 2020). Humans are exposed to these tiny plastic fragments through processes such as ingestion and inhalation and have adverse health effects such as inflammation, apoptosis, cardiovascular diseases, auto-immune conditions, chronic inflammation, and neurodegenerative diseases (Azoulay et al., 2019). Some studies showed that plastic fragments could cause tissue injury, specifically to the lungs and gut. Microplastics and nanoplastics can even cross the cell membranes, e.g., the blood-brain barrier and the human placenta. In a recent study, plastic particles were detected in the placentas of healthy pregnant women. The microplastics detected mainly were 10 μm in size (0.01 mm) and found in the placenta (both fetal and maternal) and also in the fetus membrane (Carrington, 2020). Human health hazards also include oxidative stress, cell damage, and inflammation (Vethaak and Leslie, 2016). Chemical additives and other harmful polymeric compounds associated with plastics (e.g., phthalates, lead, bisphenol A (BPA), and brominated flame retardants) also pose a threat to human and animal health (Hahladakis et al., 2018). The severe effects of exposure to low doses of BPA on animal models (mice) showed considerable stimulation of insulin secretion, followed by insulin resistance, decrease in sperm count, and disruption of hippocampal synapses. Exposure to BPA during mice's developmental stages affects their brain development (Talsness et al., 2009). Exposure to phthalates, generally to the male reproductive tract, is susceptible and can result in many reproductive disorders. Most studies on mice and guinea pigs as model organisms showed severe disorders in the male reproductive system. In a study conducted in the USA, mice infants were exposed to significant levels of different phthalate metabolites (Sathyanarayana et al., 2008), and the result showed uneven development of genitals in mice babies (Swan, 2008). The DCHP (dicyclohexyl phthalate) and DEP (diethyl phthalate) are reported to have disturbing endocrine properties (Wang and Qian, 2021). The Di(2-Ethylhexyl) phthalate (DEHP), Di-n-butyl phthalate (DBP), and Benzyl-butyl phthalate (BBP) can also interfere with the reproduction pattern of human as well as aquatic life (Wang and Qian, 2021). The lead used in thermal/heat stabilizers is also classified as a chronic compound that has long-lasting effects and can cause organ damage (Jubsilp et al., 2021).

Apart from toxic chemical additives, microplastics also act as vectors for pathogenic microbial strains, which can be fatal to the human gut system. In a report, plastic debris on the Belgian coast has been reported to have human pathogenic bacterial strains such as *Bacillus cereus*, *Stenotrophomonas maltophilia*, and *Escherichia coli* (Vethaak and Leslie, 2016). On the microplastic surfaces, these human pathogenic bacterial strains colonize to form biofilms and make their entry into freshwater, leading to human exposure and high chances of infection. Plastic litter in wet areas can also provide a substrate for mosquito larvae and act as a spreader of the Zika virus and dengue (Krystosik et al., 2020). The degree of human exposure, concentration levels, and mechanistic pathway by which microplastics and nanoplastics are affecting the human body is still not adequately understood. However, recent investigations showed that plastic pollution is an emerging human health issue. Thus, dedicated research studies are now needed to give detailed information on the hazardous effects of plastic on human health to mark efficient progress towards a sustainable environment.

7. Strategies to reduce the climate impact of plastics

Considering the direct and indirect involvement in global climate change and their severe toxicity to the environment and animal health, we need urgent strategies and actions to control the menace generated due to plastics. We need to reduce harmful greenhouse gas emissions produced during the lifecycle of plastic production and avoid marine littering to balance carbon sequestration. These bio-based plastics generally have lesser lifecycle GHG emissions than their counterparts (Zheng and Suh, 2019). It is expected that by selecting bio-based plastics instead of conventional plastics, 65.8 % population across the globe would shun 241–316 metric tonnes of CO_2 equivalent per year (Spierling et al., 2018). Two types of bio-based plastics are available on the market, including both biodegradable and non-biodegradable forms. The bio-based non-biodegradable polymers are generally derived from renewable resources. For example, bio-based polyethylene (bio-PE) is derived from sugarcane and has identical features to polyethylene which is obtained from fossil resources. These bio-based non-biodegradable polymers are also known as 'drop-in' plastic polymers as they are similar to fossil fuel-based plastic polymers (Muniyasamy et al., 2019). The second form comprises bio-based biodegradable biopolymers, which are also derived from renewable resources. They are often biodegradable and display various chemical and mechanical properties compared to their fossil fuel counterparts. The most common examples are polyhydroxyalkanoates (PHAs), thermoplastic starch (TPS), and polylactic acid (PLA) (Chen and Patel, 2012). Other groups include synthetic polymers which are derived from biomass or oil-based monomers such as polycaprolactone (PCL) and polybutylene succinate (PBS) and polymers derived from microorganisms (polyhydroxy butyrate (PHB) and polyhydroxyalkanoates (PHAs)) (Arman Alim et al., 2022). For the promotion of bio-based plastics, different effective strategies have been formulated by the European Commission (EC) and also by South Korea and Thailand (Zheng and Suh, 2019). The worldwide production of bio-based plastics reached approximately 2.05 metric tonnes in 2017 and is further projected to enhance its pace by 20 % over the coming years (European Bioplastics, 2017). Another strategy could be the low-carbon energy-based technique which can minimize the emission of GHG during plastic production. In the US, greenhouse gas emissions were reduced by 50–75 % using a low-renewable-energy-based method (Posen et al., 2017). According to an analysis conducted by Material Economics, by opting for zero-carbon or low-carbon energy sources in the manufacturing stage of plastic polymer, GHG emissions can be decreased by 50 % (Bauman, 2019). Recycling can be used as another strategy for reducing GHG, but unfortunately, the recycling percentage is abysmal around the globe. A report by "The Plastic Pollution Coalition" estimated that in the US, only 2 % of municipal plastic debris was recycled in 2018 (Cho, 2020). Interestingly, recycled plastic is one of the cheapest sources of plastic polymers and thus may fulfill the high demand of different sustainable companies (Hopewell et al., 2009).

Banning single-use plastic can also be employed as another strategy to reduce the harmful impact of plastic on the climate. Lower plastic consumption will positively affect the health of the ecosystem. Countries such as Australia, Peru, India, and France have strictly restricted the use of single-use plastics. An all-out ban was imposed for all types of plastic carry bags in New York State on 1st March 2020. The law stated "a new bag waste reduction law" in which plastic carry-bags (other than an exempt bag) became banned from distribution by anybody mandatory to collect sales tax (Bag Waste Reduction Law, 2020). In 2018 according to a United Nations Environment Programme report, almost 127 countries had passed some legislation regulating the minimal use of plastic bags. These bills and regulations include limiting the production and utilization of plastic bags, imposing a tax on them, and regulating their disposal.

27 other countries have also banned single-use plastic packaging cups, plates, and straws (Cho, 2020). The United States banned the use of

microbeads in different commercial products under the Microbead-free Waters Act of 2015 (Sharma and Chatterjee, 2017). India is also progressively working towards different strategies to protect the environment from plastic pollution. In June 2016, during World Environment Day, India announced a campaign to eliminate single-use plastic by 2022–23. Himachal Pradesh, the northern state of India, became India's first state to ban the distribution of plastic bags. From July 2022, India banned all single-use plastic products. The local government of maximum states and union territories of India had developed different legislation and strategies to eliminate the use of single-use plastic. The officials of state governments also worked on the reduction of the manufacturing of plastics by different industries by imposing different regulations and preventing the import of different plastic products (SampathKumar, 2019). However, in reality, the usage of plastic bags and products is still very high because of the citizens' casual approach to this problem, making India one of the world's top four plastic waste producers (Bhatia, 2017). Thus to solve this issue, the CIEL presented a report with possible remedies and measures for this plastic pollution crisis. These include:

(i) A complete ban on the production and usage of single-use and disposable plastic;
(ii) Stopping infrastructural growth of new ventures in gas, oil, and petrochemical production
(iii) Promotion of Zero-waste policies.
(iv) Focusing on the principle of producer responsibility
(v) Enforcement of vital targets and goals for reducing greenhouse gases from various industrial sectors, including the plastic industry.

To suggest a few measures, (i) adequate litter and recycling bins can be set up in different towns, cities, and especially on beaches to speed up the prevention and minimization of plastic pollution; (ii) citizens should effectively address the issue of plastic pollution in terrestrial and aquatic habitats; (iii) proper research should be funded and supported, and for this, research institutions, industries, and government authorities have to work in collaboration; (iv) by redesigning plastic products and developing a proper channel for their disposal, microplastics waste from cosmetics, pellets, tires, and synthetic textiles can be reduced. Above all, we need to rethink our moral responsibility to our planet.

However, it is essential to note that we must find a proper replacement for plastic in parallel to banning it. A very narrow space allows for dealing with this issue as alternatives like glass or paper is also very much energy-intensive and produces more GHG.

8. Conclusions

Plastic has nowadays become an integral part of our lifestyle ranging from the domestic and industrial sectors to coastal activities, and thus poses a considerable threat to the environment and human health. The global temperature rise and climate change are the most critical problems the world is facing today. Along with other contributors, plastic and microplastic particles contribute immensely to this climate problem. Due to multiple GHG emissions in the plastic lifecycle, the ecosystem is prone to global warming at a higher risk which would cause irrevocable damage to the ecosystem, and human lives and human rights will also suffer a considerable loss. Plastic debris is expected to increase approximately 20-fold by 2025, and oceans will be filled with plastics by 2050. >700 marine species have been adversely affected due to marine-plastic pollution, and a novel ecosystem called "plastisphere" has been generated. Plastic fragments have a toxic effect on the climate of the aquatic ecosystem as it harms marine species and disturbs the ocean's carbon sequestration cycle. By magnifying the carbon footprint in the ecosystem, humans are posing challenges to living species for their survival. Thus to avoid the consequences of plastic pollution on the climate, a cut-off of greenhouse gas emissions by around 45 % by the end of 2030 and zero emissions by 2050 have been planned.

The legislation of different plastic policies on the production, investment, and usage of plastic articles will help in this regard. The increase in carbon footprint and the rapid production of plastic should be appropriately checked and measured. Every new investment in the plastic supply must be appropriately evaluated for its impact on the climate. Different policymakers, environmental researchers, government bodies, and philanthropic fundraisers must be involved in eradicating plastic and its associated impact on the world climate and environment so that our future generation should inherit a sustainable environment for their living.

CRediT authorship contribution statement

Shivika Sharma: Writing - review & editing, Data curation. **Vikas Sharma:** Writing - review & editing. **Subhankar Chatterjee:** Conceptualization, Writing - review & editing and overall supervision of the work.

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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