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A SYNTHESIS OF THE MICRO-NANO PLASTIC WASTE IMPACT ON HUMAN HEALTH. A MEDICAL PERSPECTIVE

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Abstract: *This article presents a comprehensive synthesis of recent scientific findings on the ecological and medical impacts of micro- and nano-plastic (MNP) pollution. It highlights the pervasive presence of MNPs in the environment and their infiltration into human body through inhalation, ingestion, dermal contact, and even prenatal exposure. The study outlines the toxicological effects of plastic particles and additives, linking them to various health disorders such as endocrine disruption, respiratory and gastrointestinal illnesses, cancer, neurological and cardiovascular diseases, and immune dysfunctions. The paper also describes the challenges posed by MNPs on 12 of the Sustainable Development Goals (SDGs), emphasizing the need for systemic solutions including stricter regulations, circular economy practices, and public awareness initiatives. The research is part of the EDU4PlastiCircular project, aiming to foster education and action toward a climate-neutral and plastic-responsible future.*

Key words: *micro-nano plastic (MNP), plastic effects on human health, plastic human exposure, plastic awareness, education, EDU4PlastiCircular project.*

1. INTRODUCTION

"Plastics, including microplastics, are now ubiquitous. They are a marker of the Anthropocene, the current geological era, and are becoming part of the Earth's fossil record. Plastics have given their name to a new marine microbial habitat, the plastisphere" [1]. Recent research has estimated the plastic quantity in the seas to be between 75 and 199 million tons, despite current efforts. Depending on the methodology used, estimated annual global emissions from land sources vary. [2]. The overall amount of plastic waste in aquatic ecosystems might nearly triple from 9 to 14 million tons per year in 2016 to an anticipated 23 to 37 million tons per year by 2040, assuming a business-as-usual scenario and in the absence of necessary interventions. [3]. By using a different method, it is predicted that by 2030, the quantity would have about doubled from an estimated 19 to 23 million tons annually in 2016 to 53 million tons annually [1-4]. The world faces a plastic (including micro-(nano)plastic, MNP) pollution crisis, originating from the degradation of plastic waste materials, released in all environmental compartments and consequently in living systems, including humans. Researchers have established a correlation between MNPs and various health ailments, diminished life expectancy, and mortality. Few facts that strengths the concerned and urgent actions for prevention and awareness are supported by ecology activists, sustainability and the environment scientists, researchers, but also by medical practitioners [4-11]:

- There are three known ways to encounter or be exposed to MNPs: via the skin, ingestion of particles, and inhalation [4-6];
- MNPs threaten global social, environmental, and economic sustainability and recently, scientists revealed startling concentrations of microplastics in seafood that fishmongers sell for human consumption as well as on the sea floor [4, 7, 9, 11];
- Recently, researchers found that a variety of health harms, including respiratory diseases, cancer, and congenital disabilities, were

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associated with plastics exposure [5, 6, 10, 11];

- Early in 2024, The New York Post journal released a story claiming that microplastics are a part of the $250 billion annual health catastrophe in the United States [8, 9].

Repeatedly, we are confronted with the deleterious effects of plastic on environmental compartments and on human health. Nevertheless, as we find ourselves in the year 2025, we are recycling a mere 9% of discarded plastic while simultaneously generating an unprecedented amount of single-use plastic [10-12]. Thus, all efforts that could raise awareness of the MNP problem are more than welcome because of their expected impact at the community level and their echoes at the local, regional, national and even global level.

The paper aims to provide an inventory of scientific evidence on how MNPs are generated (source of pollution and their impact on different forms of life) and how humans are exposed to these plastic particles. The methodology used in the present article is based on literature analysis and synthesis based on references in the last five years focusing on (micro/ nano) plastic waste impact on environment and human health, just to underline the urgent need for action.

The research reported in this paper is done in the frame of the EDU4PlasiCircular project "Education for Plastic in a Circular and Climate Neutral Economy - Preventing Waste Ending Up into the Environment", Project No: 2023-1-RO01-KA220-HED-000166242. One of the project objectives is to enhance and develop the green competencies of students and higher education educators (including teaching staff and managers), while also promoting sustainable practices and increasing awareness of plastics within the context of the circular economy. This paper aims to correlate current information regarding the presence of plastics in the environment and their impact on human health, by providing an inventory of scientific evidence on how MNPs released into environment proved to have impact on human health. This approach places the educational activities (mainly dedicated to engineering students) as components of the communication process, which encompasses not merely the transmission of technical information, but also the construction of meaning within a contemporary cultural and value-based framework.

The paper presents facts and figures regarding plastics and micro/ nano-plastics into environment and their effects on human health, based on reported data. In the second part, it provides an analysis of the challenges posed by the MNPs on sustainable development goals (as general framework for sustainable development). Looking from the perspective of the educational process focusing on plastics dedicated to engineering students, the paper brings as the living center of the communication process the human beings who manufacture, use and discard plastic products, and might be affected by plastic waste once entered in environment. This emphasis on the human element highlights the importance of fostering critical thinking and creativity among students, essential skills for addressing the complexities of plastic materials in engineering. By nurturing these attributes, the educational framework can better prepare future engineers to innovate and contribute positively to sustainable practices in the industry.

2. FACTS FROM THE LITERATURE

2.1 Understanding MNP Waste generation

Plastics are synthetic polymeric materials that are chemically diverse and have a wide range of uses in contemporary life. According to various estimates, thermoplastics constitute the predominant share of plastics produced, exceeding 80%. They are synthesized by low-molecular-weight monomers, through polymerization to generate high-molecular-weight polymers Various physical processes, including extrusion, melting, and pelletization, along with chemical processes that integrate additives like antioxidants, plasticizers, and organic or inorganic dyes which modify and enhance their physical and chemical properties. Thus, plastic materials and products possess complex chemical composition and properties alongside a resilient physical framework. Moreover, the demand for plastic has experienced a consistent upward trajectory in recent decades, attributable to its affordability, efficient scalability, and longevity;

approximately 8300 different plastics are manufactured on a global scale [12, 13].

2.2 Human Exposure Routes to MNP and Plastic Additives

Once plastics are manufactured, used, and discarded, they undergo environmental degradation, releasing micro (nano)plastics and chemical additives into ecosystems [6-8]. Humans can be exposed to these particles and associated chemicals through multiple interconnected routes, each with its mechanisms and influencing factors. This highlights the critical need for being aware of the main exposure routes, the main health effects correlated with plastics waste, to understand the complex interplay of environmental, occupational, and behaviors, necessitating targeted educational activities and mitigation strategies to diminish plastic prevalence in environment and consequently human exposure and associated health risks (Fig. 1).

Inhalation - The airborne microplastics (typically those with diameters below 10 μm) represent a significant inhalation hazard due to their capacity to deposit within the distal regions of the respiratory tract, including the bronchi and alveoli. The primary sources of microplastics, facilitating exposure to airborne particles include [6-8]:

- Microfibers originating from textiles and furnishings become airborne through mechanical disturbances and can subsequently be inhaled, leading to deposition within the respiratory tract;
- Industrial Emissions as result of plastic manufacturing, recycling, and waste incineration release volatile organic compounds (VOCs) alongside microplastic particulates into ambient air. Their inhalation may induce respiratory irritation, inflammatory responses, or systemic distribution of the chemical constituents;
- Indoor Accumulation because household dust provides a reservoir for microplastics, with activities such as vacuuming and dusting acting as resuspension mechanisms that enhance inhalation exposure.

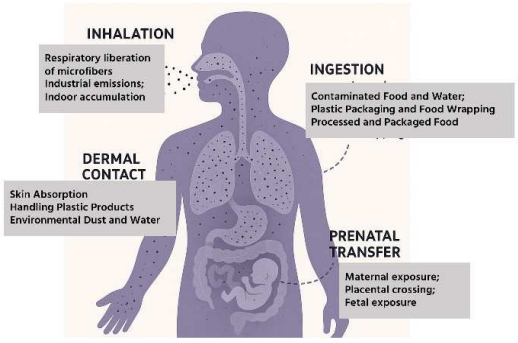

Fig. 1. Exposure routes human body to MNPs.

Inhalation of MPs, particularly those found in indoor environments, can surpass outdoor concentrations due to their accumulation from household products and furnishings, and several factors modulate the extent of exposure [8]:

- Poor indoor air quality, characterized by inadequate ventilation and high-density use of synthetic textiles, increases inhalation risks;
- Occupational settings (particularly in plastics manufacturing, recycling facilities, and textile industries) pose elevated exposure scenarios;
- Poor air quality, especially in urban and industrial environments, is typically associated with higher ambient levels of airborne particles, magnifying the potential for inhalation exposure.

In the context of this research, some examples of plastics and related particles/compounds posing inhalation risks are presented in the following [6-8]:

- Polyester and Nylon Fibers are used extensively in textiles, carpets, and clothing. During washing, wearing, or cleaning, these synthetic fibers shed microfibers that become airborne and can be inhaled;
- Polystyrene (PS) is used in disposable cups, packaging, and insulation materials. During manufacturing or incineration, styrene vapors are released into the atmosphere;
- Polyvinyl Chloride (PVC), when heated during manufacturing or waste incineration, can release volatile organic compounds (VOCs) such as hydrogen chloride and dioxins (well known as persistent

environmental pollutants), which are toxic when inhaled;
- Expanded Polystyrene (EPS), used in insulation and packaging; during manufacturing and disposal, microplastic particles and VOCs are released into the air, which workers and nearby populations can inhale.

Ingestion – Micro (nano)plastics are reported to mainly occur in food and beverages, and their ingestion is attributed to [14]:
- Contaminated food and water - MNPs are pervasive in oceans, freshwater bodies, and soils. Marine organisms (plankton, fish, and shellfish), ingest microplastics, leading to bioaccumulation throughout the food chain, ending up in human body;
- Plastic packaging and food wrapping - many food products are stored or packaged in plastics that contain additives such as BPA and phthalates. Heating or microwaving these products can increase leaching, resulting in the migration of chemicals into food and beverages;
- Processed and packaged food MNPs contaminate salt, sugar, honey, and others processed foods due to environmental pollution or manufacturing processes.

The main factors influencing the MNPs' exposure by ingestion are [14]:
- Dietary habits such as high seafood consumption;
- Food packaging as the use of certain plastics (e.g., polycarbonate bottles);
- Food processing such as heating plastic containers or wrapping.

Relevant to the topic debated are the following examples of plastics posing risks via ingestion:
- Polycarbonate (PC), used for water bottles, food containers, and baby bottles which contain bisphenol A (BPA), which may leach into food and beverages, particularly when are scratched or placed under the heat;
- Polyethylene (PE) and Polypropylene (PP) are common in food packaging, such as plastic wraps, containers, and straws. Microplastics from these materials have been detected in table salt, honey, and seafood, indicating contamination of the food chain;
- Polyvinyl Chloride (PVC), used in food packaging films for some processed foods. PVC can contain phthalates as plasticizers, which may migrate into food, especially when heated;

Dermal Contact - Although the skin is a substantial barrier, repeated contact with plastics in personal care products or plastic-treated clothing can allow certain chemical additives to leach through the skin, particularly if the epidermis is damaged. Exposure to plastics, in different forms and dimensions, takes place through various mechanisms [5-7, 14, 15]:
- Skin absorption - Chemicals such as phthalates, BPA, flame retardants, and dyes can penetrate the skin, especially when the skin barrier is compromised or when contact involves heated or damaged plastics;
- Handling plastic products - Daily contact with plastic items such as food containers, toys, textiles, or personal care products can facilitate dermal absorption of chemical additives;
- Environmental dust and water - Contact with dust containing microplastics or contaminated water during bathing, washing, or swimming can result in dermal exposure.

Exposure is influenced by factors like [5-7, 14, 15]: skin integrity as damaged or sensitive skin may absorb chemicals more readily; duration and frequency of contact because prolonged or repeated contact increases risk; chemical properties as lipophilic (fat-soluble) chemicals like phthalates can easily penetrate the skin. Furthermore, in the following examples are presented of plastics and additives that pose dermal risks [5-7, 14, 15]:
- Polyvinyl Chloride (PVC) contains phthalates as plasticizers, which can migrate to the surface and penetrate the skin upon contact. Workers handling PVC products or consumers wearing PVC clothing may absorb these chemicals;
- Polycarbonate (PC), used in optical lenses, safety helmets, and some baby bottles. BPA can leach from PC plastics, and skin contact may allow absorption, especially if the skin is damaged or if plastics are heated;
- Textile fibers (polyester, nylon), as microfibers shed from synthetic textiles can

settle on skin (or be inhaled), and chemical additives or residual monomers from fibers can penetrate the skin.

- Dyes and flame retardants in textiles contain chemicals such as halogenated compounds or brominated flame retardants, which can leach and penetrate the skin during prolonged contact.

Prenatal and neonatal transfer - Recent studies have identified plastic particles in the placenta, breast milk, and amniotic fluid, demonstrating in utero exposure. The developing baby's exposure before and after birth is attributed to [5-8]: maternal exposure as pregnant individuals inhale or ingest microplastics from the environment; MNPs can cross the placental barrier, entering fetal circulation; MNPs particles have been detected in placental tissue, amniotic fluid, and even meconium (the baby's first stool), suggesting in utero exposure. This area of research is still evolving, but the evidence is clear: plastics are not just an environmental issue.

Leaching and Migration of Chemical Additives - Chemical additives such as plasticizers (e.g., phthalates), bisphenol A (BPA), flame retardants, and dyes are often not chemically bound to the plastic matrix, making them susceptible to leaching in time. Factors that enhance leaching and implicitly human exposure include [15] heat from cooking, microwaving, or exposure to sunlight accelerates chemical migration; mechanical stress from bending, cracking, or aging of plastics facilitates leaching; pH and chemical environment from acidic or alkaline conditions that can increase the migration of additives.

Once leached, these chemicals can enter the human body potentially accumulating over time and exerting toxic effects. In the following, examples of plastics and conditions that promote leaching are presented:

- Polycarbonate (PC) contains BPA that can be liberated into food or water, especially when bottles are exposed to heat or UV light;
- Polyvinyl Chloride (PVC) contains phthalates, which can migrate into food, especially in fatty foods stored in PVC containers or wrappings;
- Polypropylene (PP), used in microwaveable containers, can cause residual monomers or plasticizers to migrate into food or beverages when heated;
- Polyethylene (PE), used in plastic bags and wraps, accelerates the migration of residual chemicals when heated or subjected to mechanical stress.

Environmental Persistence and Bioaccumulation - Microplastics are highly persistent in the environment, resisting to natural degradation due to their chemical stability and resistance to environmental conditions. On the polymers chains at particles' surface other pollutants can be adsorbed, such as heavy metals and persistent organic pollutants (POPs), forming complex mixtures that pose additional risks upon human exposure. These substances can bioaccumulate in organisms, increasing exposure levels as they move upward the food chain. For example, microplastics derived from Polyethylene and Polypropylene are the predominant polymers identified in microplastic pollution. They can carry adsorbed toxins, such as heavy metals, which can bioaccumulate in marine organisms and ultimately affect humans consuming seafood. Another category of chemicals, Polybrominated Diphenyl Ethers (PBDEs), used as flame retardants in plastics and textiles can easily be released into the environment and accumulate, especially through ingestion of contaminated foods or inhalation of dust.

2.3. Pathologies Resulting from MNPs in Human Body

The presence of MNPs and their chemical additives within the human body has been correlated with a wide array of health disorders. These pathologies arise from direct exposure during manufacturing, use, or disposal, as well as from the accumulation of microplastics and chemical residues in tissues over time. Here, we explore some of the key health harms and provide specific examples of plastics involved, based on scientific data [5-8, 14, 15, 19, 20]. The presence of MNPs particles and chemical additives can trigger a range of adverse biological effects as synthetically presented in Fig. 2.

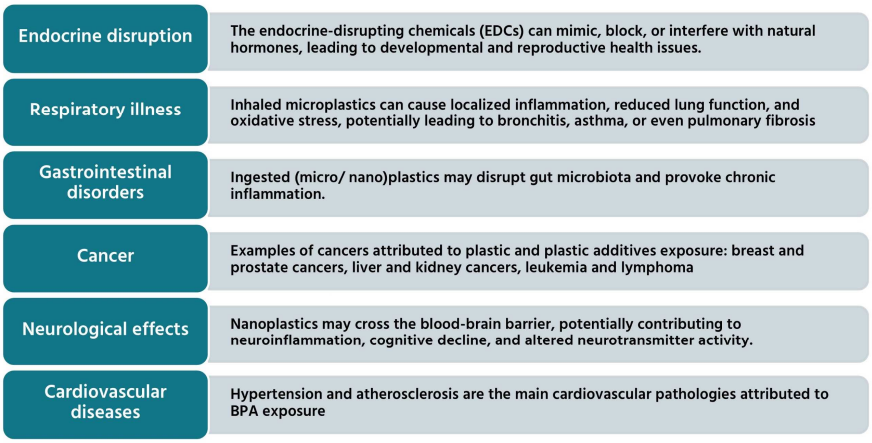

Fig. 2. Key health harms caused by plastic exposure

Endocrine disruption - Many plastics contain chemicals that interfere with hormonal systems, termed endocrine-disrupting chemicals (EDCs) leading to developmental and reproductive health issues. Additives like bisphenol A (BPA), used in polycarbonate (PC), and phthalates (Di(2-ethylhexyl) phthalate (DEHP), used in polyvinyl chloride (PVC) are often introduced to enhance plastic flexibility, but they mimic or block hormone function. They have been linked to reduced fertility, altered sexual development, and increased risk of hormone-dependent cancers (e.g., breast, prostate). Also, they act as obesogens (chemicals that promote fat accumulation) by interfering with the hormonal regulation of metabolism. Once the chemical binds to estrogen receptors, it affects adipogenesis and insulin sensitivity.

Respiratory illness – Once entered in air, plastic MNPs might be inhaled, ausing localized inflammation, reduced lung function, and oxidative stress, potentially leading to bronchitis, asthma, or even pulmonary fibrosis. Chronic exposure may worsen conditions such as asthma and chronic obstructive pulmonary disease (COPD).

Gastrointestinal disorders – Through ingestion, MNPs may disrupt gut microbiota and provoke chronic inflammation. For example, fragmented polystyrene and its residual monomer, styrene, have been linked to tissue damage and carcinogenic effects in animal studies. The chronic ingestion of microplastics may aggravate intestinal inflammation. Animal studies show microplastic ingestion can result in liver enlargement, inflammation, and tissue scarring.

Cancers - Some plastic additives, such as certain phthalates and styrene, are classified as potential carcinogens, increasing the risk of different forms of cancer. Breast and prostate cancer due to their estrogenic activity, chemicals like BPA and styrene may promote hormone-sensitive tumor development. Liver and kidney cancers because of the persistent exposure to vinyl chloride (from PVC) or other monomers have been linked to hepatic and renal carcinogenesis. Leukemia and lymphoma to workers exposed to industrial plastic compounds have shown higher rates of blood cancers, potentially due to genotoxic effects.

Furthermore, certain plastics or associated chemicals (additives, residual monomers, etc.) are classified as potential carcinogens or have been associated with increased cancer risk. Styrene in Polystyrene is considered as possibly carcinogenic substance (Group 2B), according to the International Agency for Research on Cancer (IARC). It has an increased risk of gastrointestinal and hematological cancers with chronic exposure. Dioxins are unintentional pollutants released by PVC heating/incineration during manufacturing and disposal. Dioxins are highly toxic, persistent pollutants that accumulate in body fat tissues. Chronic exposure has been linked to increased risk of soft tissue sarcomas, lymphomas, and breast cancer.

Neurological effects - NPs may cross the blood-brain barrier, potentially contributing to neuroinflammation, cognitive decline, and altered neurotransmitter activity, especially

when associated with heavy metals or polycyclic aromatic hydrocarbons (PAHs) ab-/ adsorbed onto plastic particles surface. Exposure during pregnancy or early childhood may lead to neurodevelopmental issues, developmental delays, and behavioral problems. Cognitive impairment - Studies suggest NPs may cross the blood-brain barrier, potentially contributing to memory loss or reduced cognitive function. Developmental delays - Prenatal exposure to endocrine-disrupting chemicals (like BPA or phthalates) have been linked to ADHD, lower IQ, and behavioral disorders in children. Neuroinflammation is because MNPs may induce oxidative stress in brain cells, triggering inflammatory responses that resemble early mechanisms in neurodegenerative diseases. Among chemicals demonstrated to have adverse effects on the neurological system, styrene in Polystyrene (PS) must be exemplified, which is used in disposable cups, food packaging, and insulation materials. Styrene vapors can be inhaled during manufacturing or from aging products, which have been demonstrated to have neurotoxicity leading to cognitive deficits, headaches, and depression. It also has potential links to neurodegenerative diseases like Parkinson's or Alzheimer's with chronic exposure. The BPA in Polycarbonate plastics, an endocrine disruptor, has been linked to impaired neurodevelopment, especially in children.

Cardiovascular diseases - Hypertension and atherosclerosis are the main cardiovascular pathologies attributed to BPA exposure. Also, the persistent organic pollutants (POPs) absorbed onto MNPs, can induce inflammation, oxidative stress, and vascular dysfunction.

Immune and inflammatory disorders - Some plasticizers may dampen immune response, increasing susceptibility to infections. Microplastics and leached chemicals can provoke immune responses, leading to allergies, asthma, or autoimmune conditions.

3. AN ANALYSIS OF THE CHALLENGES POSED BY MNPs ON THE SUSTAINABLE DEVELOPMENT GOALS (SDG)

An inventory of MNPs waste and pollution ways can form the basis for elaborating measures to reduce its impact on human health, especially when considered from both an ecological and a medical perspective. This approach links the source of pollution to its effects on living systems, enabling targeted, effective solutions. An ecological perspective focuses on the environmental pathways of MNPs and their effects on ecosystems, which in turn impact human health. It starts with a comprehensive inventory to understand the scope of the problem.

Source and distribution of plastics - An inventory helps to identify the primary sources of MNP pollution, such as tire abrasion, synthetic textiles, plastic packaging, and industrial waste. It tracks their transport through air, soil, and water, showing how they become ubiquitous pollutants. This information is crucial for developing policies that target high-impact industries and sources.

Ecosystem disruption - MNPs don't just exist in the environment - they interact with it. They can alter soil properties, disrupt microbial communities, and interfere with nutrient cycles. In aquatic environments, they can absorb and transport other pollutants, like heavy metals and organic chemicals, etc.

This process, known as bioaccumulation, is a significant ecological concern.

Food chain contamination - By entering the food chain at the lowest levels, MNPs are consumed by marine life and other organisms. As larger animals eat smaller ones, the concentration of plastics and associated toxins increases, eventually reaching the food we eat.

The medical perspective focuses on the direct and indirect health effects of MNPs on humans. It builds on the ecological inventory by analyzing how exposure to these plastics translates into physiological harm.

Exposure pathways - An inventory provides data on the types and concentrations of MNPs present in food, water, and air, as the main human exposure routes. Once ingested or inhaled, these particles can penetrate biological barriers and accumulate in tissues and organs. Smaller particles can more readily penetrate these defenses, allowing nanoparticles to access the bloodstream and even traverse the blood-brain and placental barriers.

Physiological effects - Once inside the body, MNPs can cause a range of adverse health effects.

Their physical presence can trigger inflammation and oxidative stress. More significantly, plastics can leach hazardous chemical additives like phthalates and bisphenol A (BPA), which are known endocrine disruptors, interfering with the hormonal system, and potentially leading to reproductive toxicity, developmental abnormalities, and an increased risk of diseases like certain cancers.

Causality and risk assessment - While more research is needed to establish definitive causal relation between specific MNP exposure levels and human health, an inventory provides the essential data for epidemiologists and toxicologists to conduct meaningful studies. By correlating MNP levels in the environment with disease prevalence in population, we can better assess the risks and develop public health advisories and regulations.

The combined ecological and medical inventory is essential for developing effective measures aligned with the Sustainable Development Goals (SDGs). A comprehensive inventory would contribute to multiple SDGs, as centralized in Table 1 (additional to the findings of [4]). Considering the serious and urgent problem of MNPs affecting life, we centralized recent evidence of MNPs (based on recent literature) providing information on their challenges posed on the United Nation Sustainable Development Goals (SDG). Literature review has identified 12 of the 17 SDGs that are impacted by MNPs pollution [4].

Table 1

Challenges posed by MNPs on SGDs implementation (extend from [4]).

SDG Goal	MNPs negative impacts	Evidence based on the literature
1. Poverty ending everywhere	- Impact the services ecosystem; - Economic impacts on communities (e.g., vulnerable populations).	- Plastics waste (macro/ micro/ nano forms) in sea or ocean's coastal areas affect most the ecosystem services [16]; - Communities with high risk of poverty are most affected by the plastic industry [17]. No economic or ecologic indicators directly related to plastics in SDG 1;
2. Eliminate hunger, ensure food security, enhance nutrition, and advance sustainable agriculture	- Presence in food packaging, agricultural soils, fruits and vegetables, fish and shellfish; - High risk to human health via food ingestion;	- This is the most affected domain caused by plastic pollution due to the extensive use of it in packaging. The presence in soil is due to over exploitation of plastics and plastic waste mismanagement [18]. Compost is a major source of MNPs. Polluted terrestrial environments "can act as a source and distribution pathway to the aquatic systems" (rivers, sea, ocean) [18];
3. Promote health and well-being for individuals of all ages	- Human health is affected as result of ingestion, inhalation, dermal contact; - Existence of MNPs in humans' body	- Effects on human health refers by "damaging cells process or inducing inflammatory and immune reactions" [5-8, 20] - MNPs particles were discovered in the placentas and unborn children, so individuals are exposed to MNPs before birth [19]
6.-Guarantee the accessibility and sustainable administration of water and sanitation for all populations.	- Presence in drinking water and wastewater;	- "The presence of micro-nano plastics in drinking water from treatment plants varies widely from undetectable to >900 particles/L and largely depends on water sources, plant design, and methods used for analysis" [4]; - The inventory of MNP pollution in water bodies is crucial for developing strategies to ensure access to safe drinking water and protect aquatic ecosystems [1, 5-7].
7. Ensure sustainable, and contemporary energy for all	- Plastic incineration results in the release of greenhouse gas emissions that contribute to environmental pollution and impacts associated with climate change;	- "Incineration of plastic waste used in waste-to-energy systems contributes to greenhouse gas emissions" [21]; - Incineration of plastic waste generates atmospheric pollution due to harmful gases emissions [4];

SDG Goal	MNPs negative impacts	Evidence based on the literature
9. Establish robust infrastructure, advocate for inclusive and sustainable industrial development, and cultivate innovation.	- Innovative approaches for implementing circular economy principles; - Innovation for alternative materials and fuels;	- Innovative approaches "for sustainable bio-based alternatives to fossil fuel–based plastics to accelerate the implementation of circular economy principles" [22, 23]. - Development of bioplastic materials [24, 25].
10. Mitigate inequality both inside and among countries	- The transfer of plastic waste from economically developed nations to less developed countries has been regarded as a form of waste pollution migration.	- Identifying a global plastic waste trade [26, 27]. - In the absence of proper recycling facilities, a significant portion of this imported plastic waste ends up in landfills, is openly burned, or pollutes local and regional environment, including rivers and oceans. Communities living near informal dump sites in low-income countries are disproportionately affected. - Exposure to toxins from burning plastics and contaminated water "can lead to a range of health problems, including respiratory issues, skin diseases, and an increased risk of cancer" [5-7, 14, 15]
11. Ensure that urban environment is inclusive, safety, resilience, and sustainable.	- The unregulated disposal of MNPs characterized by insufficient waste management frameworks obstructing urban infrastructure.	- Providing data on MNPs health impacts directly supports the goal of reducing exposure to hazardous chemicals and environmental pollution. [1-7, 24-28].
12. Ensure sustainable consumption and production patterns	- Global plastic production is unsustainable; mismanagement of plastic waste; ignore responsible consumption and the recycled/reuse potential;	- An inventory of plastic waste substantiates policies for sustainable consumption and production patterns, promoting the adoption of biodegradable alternatives, and improving waste management systems are solutions for responsible consumption and reducing MNPs [1,6, 37,36, 44].
13. Implement immediate measures to address climate change and its effects.	- Each stage of the plastic life cycle results in the emission of greenhouse gases.	- MNPs "are derived from fossil fuels and they account for 6% of global oil consumption" [28]; - MNPs and "greenhouse gases emissions are inter-connected within each stage of the plastic life cycle, from production to transportation to waste disposal, contributing to climate change" [28, 29].
14. Conserve and benefit from the oceans, seas, and marine resources sustainably.	- This is the only SDG that addresses MNPs impact reduction [4] - Significant efforts are necessary to mitigate emissions impacting marine and freshwater ecosystems.	- This SDG is particularly relevant as marine MNP pollution is a major threat. Evidences of the pollutions with MNPs are provided by [1, 3, 16, 17, 29]; - An inventory of MNPs pollution provides the baseline data needed to monitor and mitigate marine pollution;
15. Protect, restore, and promote the sustainable use of terrestrial ecosystems, (forest resources sustainably, desertification, and prevent/ reverse land degradation and biodiversity loss).	- MNPs and plastic waste mismanagement	- Plastic waste is the source of extensive land and soil pollution in urban and rural areas, protected zones; [30, 31]; - MNPs "affect soil physical and chemical properties, microbial and enzymatic activity, plant growth and have adverse ecotoxicological effects on fauna" [30, 31]; - The presence of MNPs in terrestrial ecosystems is associated with inadequate waste management, particularly due to leakage, the application of biosolids to agricultural soils, and the atmospheric deposition of microplastics, which has been observed even in remote regions [30, 31].

By leveraging this integrated perspective, measures can move beyond simple cleanup efforts to address the root causes of the problem. This includes systemic solutions as stricter chemical regulations that mandate the use of safer, less toxic additives in plastic production; extended producer responsibility regulations that mandate corporations to assume accountability for the complete lifecycle of their plastic products; investing in innovative waste management and recycling technologies to prevent plastics from entering the environment; advocating for a circular economy that emphasizes the reuse and recycling of plastics, hence diminishing the overall demand for new plastic manufacture; public education campaigns raise awareness about the health and environmental risks of plastic pollution and encourage behavioral changes.

4. CONCLUSIONS

The research based on the literature review has underlined the following main conclusions:

1. MNPs pose a major threat to human health, being present in air, water, food, and even inside the human body, including in blood and the placenta of pregnant women;
2. Exposure to MNPs is linked to multiple medical conditions, such as endocrine disorders, respiratory and gastrointestinal diseases, cancer, neurological and cardiovascular issues, and immune system dysfunctions;
3. The ecological impact of MNPs is profound, affecting biodiversity, disrupting food chains, and contributing to ecosystem degradation;
4. Plastic pollution negatively affects the achievement of 12 out of the 17 Sustainable Development Goals (SDGs), highlighting the systemic nature of the problem and the need for an integrated approach;
5. Proposed solutions include stricter regulations, promotion of Circular Economy practices, and environmental education, all essential for reducing plastic pollution and protecting public health;
6. The EDU4PlastiCircular [32] project actively contributes to public awareness and education, providing a framework for concrete actions toward a sustainable and plastic-responsible future.

Urgent actions should be taken, including those in the research and development field of MNPs. The main findings of the research are:

1. Widespread presence of MNPs, which are pervasive in the environment and have infiltrated air, water, soil, and food chains. They are now found in human tissues, including blood, placenta, and breast milk;
2. The literature demonstrates multiple human exposure routes to MNPs through inhalation, ingestion, dermal contact and prenatal transfer;
3. Health impacts of MNPs and additives exposure to MNPs and their chemical additives (e.g., BPA, phthalates) is linked to different types of effects as: endocrine disruption, respiratory and gastrointestinal illnesses, cancer, neurological disorders and developmental delays, cardiovascular diseases, immune and inflammatory conditions;
4. MNPs resist degradation, absorb other pollutants, and bioaccumulate in ecosystems, posing compounded risks to both wildlife and humans.

Furthermore, the impact of MNPs pollution on Sustainable Development Goals (SDGs) negatively affects 12 of the 17 SDGs, including those related to health, water, food security, climate action, and biodiversity. Thus, there is urgent need for systemic solutions. The article advocates educational and research initiatives, as the EDU4PlastiCircular project is highlighted as a key initiative promoting awareness and action toward a climate-neutral and plastic-responsible future [32].

The paper is related to the development of the EDU4PlastiCircular project: “Education for Plastic in a Circular and Climate Neutral Economy - Preventing Waste Ending Up into the Environment” (Erasmus+ 2023-1-RO01-KA220-HED-000166242), founded with support of the European Commission. This paper and the communication reflect the views of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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O sinteză a impactului deșeurilor micro- și nano-plastice asupra sănătății umane. O perspectivă medicală

Acest articol oferă o sinteză cuprinzătoare a celor mai recente descoperiri științifice privind impactul ecologic și medical al poluării cu micro- și nano-plastice (MNP). Se evidențiază prezența omniprezentă a MNP-urilor în mediu și infiltrarea lor în corpul uman prin inhalare, ingestie, contact dermic și chiar expunere prenatală. Studiul descrie efectele toxicologice ale particulelor de plastic și ale aditivilor, asociindu-le cu diverse afecțiuni precum dereglări endocrine, boli respiratorii și gastrointestinale, cancer, afecțiuni neurologice și cardiovasculare, precum și disfuncții ale sistemului imunitar. Din perspectivă ecologică, lucrarea analizează persistența MNP-urilor, bioacumularea și perturbarea ecosistemelor. De asemenea, evaluează provocările pe care MNP-urilor le ridică în implementarea a 12 dintre Obiectivele de Dezvoltare Durabilă (ODD), subliniind necesitatea unor soluții sistemice, inclusiv reglementări mai stricte, practici de economie circulară și inițiative de conștientizare publică. Cercetarea face parte din proiectul EDU4PlastiCircular, care urmărește promovarea educației și acțiunii pentru un viitor neutru din punct de vedere climatic și responsabil față de plastic.

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