Influence of Plastic Waste Management on the Environment: A review

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Plastics have become a modern-day nuisance to the environment and man due to improper management at their end-of-life. The structure and additives in fossil-based plastics make them non-biodegradable and, therefore, can persist in the environment for hundreds of years. Since a small percentage of plastic waste is recycled annually (9%) most of this plastic waste is being managed by open-air incineration or disposal in landfills where these additives can easily contaminate the air, soil, and water apart from the fact that a lot of these plastic waste find their way into our water bodies resulting to a lot of harm to the Eco-system. Recycling of plastic is an effective means of tackling the menace of plastic pollution, with chemical recycling as the most effective recycling process as it completely removes the waste plastic from the environment. Manufacturing and use of bioplastics like Polylactic acid, a good substitute for fossil-based polymer polyethylene terephthalate (PET), is a welcome development with the People's Republic of China championing in the production. Legislative tools have been enacted in countries across the globe banning the use and manufacturing of single-use plastic bags. The implementation of this legislative move has been effective in some countries like the People's Republic of China, Morocco, and Rwanda. Nigeria enacted the Plastic prohibition bill banning the manufacturing, use, and importation of all plastic bags in May 2019. This ban does not affect the behavioral and plastic management system in Nigeria as plastic bags are still used in cities across the country, littered in waterways and landfills. Therefore, there is a need to review the bill to include waste generation and management. Emphasis should also be placed on the production, and use of cost-effective bioplastic polymers and products.
Keywords: Plastics, pyrolysis, waste management, recycling, bio-plastics, environmental pollution

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INTRODUCTION

Plastics have excellent properties such as light weight, low thermal and electrical conductivity, cheap and excellent durable (Thompson *et al*., 2009; Rodriguez, 2023; Kibria *et al*., 2023) which makes them suitable for use in every sector of life such as agriculture, building, food industry, packaging industry, medicine, automobiles, building construction, communication electronics (Thompson *et al*., 2009; European Commission, 2021; Moranda & Paladino, 2023). In recent times, plastics have been uses as good substitutes for other materials such as wood, metals, light ceramics, and glass for the production of many products (Schyns & Shaver, 2020; Oladele *et al*., 2023). A major challenge is that about 40% of plastic product is short lived of less than one (1) month (Hahladakis *et al.*, 2018; Organization for Economic Co-operation and Development, (OECD), 2022; Kabeyi & Olanrewaju, 2023) especially the packaging industry which plastics are mostly used just once and thrown away.

According to Plastic Oceans (2022), a global estimation of 500 billion plastic bags is used and thrown away every year. The global rapid increases in human population, incessant urbanization, and rapid economic growth have increased the consumption and production of plastic waste at a precarious rate. From the 1950s to the 1970s, few amounts of plastics were produced, and these plastics were properly managed, this tripled from the 1970s to 1990s. As at the 2020s, over 400 million metric tons of plastics are produced annually (Schyns & Shaver, 2022; United Nations Environmental Programme, (UNEP), 2023), and this is estimated to increase to 1,100 metric tonnes by 2050 (Geneva Environment Network, 2023; UNEP, 2023).

In 2021, the estimated worth of plastic produced was $593 billion and this is estimated to increase to $750.1 billion by 2028 with an increase rate of 3.4% between 2021 and 2028 (Oladele *et al*., 2023). The demand for plastic is also increasing and is projected to increase by 37% within the next decades which amounts to about 100 million metric tonnes of plastics. Despite the huge quantity of plastics produce yearly, only about 9% of these materials are recycled globally (OECD, 2022; UNEP, 2023). These plastics at their end of life find their way to the environment, dump sites, water bodies and incinerators.

Plastics are petrochemical hydrocarbons with additives such as stabilizers, Oxidants, and flame-retardants making them have a long half- life (it takes about 4500 years to degrade) (Geyer *et al*., 2017; United Nations, 2021; Harris, 2023) and non-biodegradable thereby persisting in the environment. A huge amount of energy required, and a lot of greenhouse gases is evolved during the production process (OECD, 2023). Zheng *et al*. (2023) reported that in the U.S alone, an estimation of 3.2 quadrillion Btus of energy is used in the production of plastics per year and 104 $MMTCO_2$ equivalent greenhouse gas is produced.

Plastics are made from by-products of petroleum and are mainly of two types: thermoplastics and thermosetting. Thermosetting plastics, also called engineering polymers, are cross-chained structured which becomes stronger and harder when heated. Examples of thermosetting plastics are acrylonitrile butadiene styrene, polyurethanes, and phenolic resins. They have great corrosion resistance, high mechanical strength, and thermal stability (Kibria *et al*., 2023; Oladele *et al*., 2023). These properties make them applicable in the electronic industry and automobile industries, while thermoplastics are branched, or liner structured and get soft when heated. Examples are polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), high-density polyethylene terephthalate (HDPET), low-density polyethylene terephthalate (LDPET), polyvinyl chloride (PVC), and polystyrene (PS) (Alabi *et al*., 2019; Kibria *et al*., 2023; Oladele *et al*., 2023). These polymers are the most commercially produced polymers globally with polypropylene (PP) having 68 mt, polyethylene (PE) 166mt, polyethylene terephthalate (PET) 33mt, polyurethanes (PU) 27mt, and polystyrenes (PS) 25mt (Zheng *et al.*, 2023). Thermoplastics are mostly used in the production of cups, plates, bags, bottles, packaging materials, and toys mixed up in the waste mainstream.

PET, PE, and PP are the most recycled polymers with occupies a large percentage of 95.2% of the recycled materials (Kökkılıç *et al*., 2022; Zheng *et al.*, 2023). Generally, the municipal solid waste contains a large amount of plastic, of which polyvinyl chloride (PVC) at 6%, polystyrene (PS) at 9%, polyethylene terephthalate (PET) at 10%, polypropylene (PP) at 14%, high-density polyethylene (HDPE) at 19%, low-density polyethylene (LDPE) at 23% (Mibei *et al.*, 2023). Knowing the type of plastic is vital in determining the method of recycling the waste plastic since all polymers have different mechanical, chemical, and physical properties and therefore would have different recycling conditions (Murthy *et al.*, 2020; Dhanalakshmi *et al*., 2022).

This review provides insight into the effects of plastic waste on man, marine environments, land, and air. The management techniques for plastic waste, innovations on bioplastics in tackling plastic pollution, and analysing the pros and cons of the use of bioplastic. A critical analysis on the policy and legislation banning the use of single-use plastic bags in Nigeria was conducted providing an insight into its level of implementation compared to similar legislations in other countries. This analysis could be useful to government officials on the tackling the ravaging plastic pollution crisis.

EFFECTS OF PLASTIC WASTE ON THE ENVIRONMENT

Water Pollution

In recent times, there has been a rise in concern about the increase in deposition of plastic in the ocean and other water bodies. A forecast has shown that by 2050 the mass of plastics found in the ocean, will be more than fish (Letcher, 2020). The percentage of sea birds with plastic found in their intestine has grown to 90% (Wang, 2021; Live Science, 2022). Plastic particles have been found in human blood (Ocean Care, 2022; Leslie, 2022).

As reported by the UNEP (2023), 75 -199 million tonnes of plastic are present in the ocean and, an average of 8 million tonnes of plastics finding their way to the oceans annually, and about 5 trillion pieces of plastic objects floating on the oceans.

Diana *et al*. (2020) reported that plastic waste poses harm to marine animals through ingestion, and entanglement causing restriction of movement and consumption of additive leaching from plastic. Studies by Koongolla *et al*. (2019), Kilic (2022), Lin *et al*. (2023), and Riaza *et al*. (2023) on fishes revealed that plastic is present in the guts, gills, and intestines of some examined fishes indicating that these plastics were unintentional consumed as food thereby exposing them to plastic additives. Though, not much is known about the effects of consuming plastic on humans, plastic is known to cause gastrointestinal obstruction, translocation and development of oxygen-reactive species, ulcers, laceration, and death among marine animals (Diana *et al*., 2023).

Land Pollution

Plastics have been found in unbelievable places, like deserts and inhabitable places (The Guardian, 2017; Li *et al*., 2022; Akanyange *et al*., 2022). Over 20% of waste found its way to landfills due to difficulty in sorting and separating these plastics from the main waste stream and separation from other materials during recycling. Researchers have proven that the illicit deposition of plastics on the soil causes several health issues and decreases soil fertility (Ferdous, 2021; Stubenrauch & Ekardt, 2022; UNEP, 2022). As reported by Alabi *et al*. (2019), chlorinated plastics leach toxic chemicals into the soil, thereby contaminating the groundwater and the soil resulting in a negative impact on the ecosystem. They also reported that during microbial degradation of the plastic, harmful greenhouse gases evolved into the atmosphere contributing to global warming.

Air Pollution

The extraction process of fossil fuel for the production of plastics releases toxic chemicals such as benzene, methane, H_2S, and volatile organic compounds (Sarkingobir *et al*., 2021; Adebiyi, 2022). Also, the incineration/burning of plastic waste produce hazardous environmental pollutants which contaminate the atmosphere. Some examples of hazardous chemicals emitted are heavy metals, furans, Dioxins, Carbon (ii) oxide, volatile organic compounds, and microplastics (Verma, 2016; Sarkingobir *et al*., 2021; Takada & Bell, 2021). These harmful substances cause harm to plants, animals, and humans. The inhaling of carbon (ii) oxide causes suffocation and chronic respiratory health problems in human, heavy metals are neurotoxin, and Volatile Organic Compounds (VOCs) are carcinogenic (Sarkingobir *et al*., 2021).

Effect of Plastic Pollution to Man

Most food packaging materials are made from plastics such as PET which is impregnated with Antimony as a catalyst during the polymerization process. Antimony tends to migrate into beverages (Oyen *et al.,* 2016; Montserrat, 2020; Carneado *et al., 2023*). Oyen *et al.* (2016) also conducted some experiments on electronic plastic waste. They discovered that plastics from electronic waste contained high concentration of cadmium (2016 ppm), lead (1124ppm), bromine (1985 mg/kg) and antimony (1356mg/kg), which exceeded the recommended limits. Antimony triode is believed to be carcinogenic to humans, and excess exposure might lead to lungs damage, skin irritation, and stomach problems (Oyen *et al.,* 2016; Saerens *et al*., 2019). Exposure to excess antimony can lead to reproductive problems (Copper & Harrison, 2009; Oyen *et al.,* 2016). Lead exposure leads to cardiovascular problems, high blood pressure and kidney damage. It also causes miscarriages and stillbirth in pregnant women (World Health Organization, WHO, 2023). Exposure to small dose of Cadmium over a long period of time leads to kidney problems like kidney stone and lung damage (Oyen *et al.,* 2016; Genchi *et al*., 2020).

MANAGEMENT OF PLASTIC WASTE

Refuse, Reduce, Reuse, Repurpose and Recycle

The 5 R's (refuse, reduce, reuse, repurpose, and recycle) are steps that ensure that waste is properly managed, reducing the amount of waste plastics ending at landfills, with recycling as the last action to take in waste management. Refuse deals with rejecting the use of plastic when possible. For instance, plastic packaging bags could be replaced with more biodegradable paper bags, reject the use of disposable plastics for reusable plastics, and rejecting the use of non-recyclable plastics. Plastics can be reduced by avoiding all unnecessary use of plastics. Groceries can be bought in bulk to reduce the use of plastic packaging and take a reusable shopping bag when shopping. Reuse involves the conscientious reuse of plastics. Reusable cutleries, plates, cups, and packaging materials could be used in place of single-use plastics, which are thrown-away after use. When refusing, reducing, and reusing plastic material seems difficult, and then repurposing comes in handy. Repurposing involves the use of an item meant for a particular purpose for another purpose. For instance, converting plastic bottles into planters and creating bottle pen and pencil holders from plastic bottles. The last 'R' represents recycling of waste plastic. Recycling involves the total conversion of plastic to different products such as fuel, and other chemicals (Geyer, 2020; Balwan *et al*., 2022).

Mechanical Recycling of Plastics

Mechanical recycling of plastic is the most commonly used method for recycling waste plastics (Ragaert *et al.,* 2017; Zheng *et al.,* 2023). Mechanical recycling of plastic involves the conversion of plastics into secondary products or raw material without altering its chemical components. The mechanical recycling of plastics involves the collection of the plastic waste, sorting according to types and colour (manually and automatically), shredding into smaller bits, washing, and elimination of impurities. These steps might follow a different order or be performed several times depending on the source and composition of the plastic waste. (Ragaert, 2017; Schyns & Shaver, 2021).

The use of recycled plastics has been proven to be three times more efficient as regarding the amount of greenhouse gas emission compared to manufacturing from virgin plastics. Mechanical recycling is faced by the challenges of inconsistent quality products, degradation of mechanical properties and the challenge of sorting (Letcher, 2020). Mechanical recycling is limited to a single feed stock, therefore, must be sorted into types and colour hence, several detectors such as Near-Infrared spectroscopy (NIR) and Ultraviolent-visible (UV-Vis) is needed. These detectors have the limitation to detect polymers which have similar chemical properties but different mechanical and physical properties. This blend can result to incompatibility in the process regarding the temperature for melting the mixture and the entire extrusion process (Schyns & Shaver, 2021).

Recycled plastics have lower mechanical strength due to degradation during use before recycling, repeated heating and extrusion (Jin *et al*., 2023; Zheng *et al.,* 2023). Therefore, additional additives and virgin plastics needs to be added in order to increase the quality to achieve the desired strength. Some plastic textiles and packaging with multi-layers have several types of polymers and cannot be easily separated mechanically are also difficult to recycle mechanically (Zheng *et al.,* 2023).

According to Oyen *et al.* (2016), waste plastic from Automobiles and electronic materials are impregnated with antimony and bromine as flame retardant thus cannot be recycled using mechanical recycling method. They also emphasized that one of the main problems of mechanical recycling industry is the unknown history and the composition of the recyclate, thus additional analysis has to be done making recycled plastic more expensive than virgin plastics.

Mechanical recycled plastics has been effectively used as replacement of wood in furniture, replacement of bitumen in asphalt mixtures in construction of roads and bridges, production of fabrics, mixed with concrete and mortars for construction purposes, production of Television backseats, as a thickening agent in liquid lubricants, and for multilayered packaging materials (Ragaert, 2017; Schyns & Shaver, 2021).

Thermal Recycling of Waste

The thermal recycling of plastic waste involves the direct heating of plastic waste to produce thermal energy (Bujak, 2015; Kijo-Kleczkowska & Gnatowski, 2022; Moranda & Paladino, 2023). Plastics contains a complex mixture of different kind of base resin and additives such as plasticisers, additives, UV-stabilizers, antistatic agents, cross-linking agents and colouring agents, which are usually uncompact able with each other. However, some environmental pollutants such as polycyclic aromatic hydrocarbons (PAHs), Dioxins, heavy metals, Volatile organic compounds (VOCs), Poly chlorinated dibenzodioxins (PCDDs), Polychlorinated dibenzofurans (PCDBFs), which are carcinogenic and have the ability to bio accumulate in fishes and contaminate the food chain are produced during thermal recycling of plastic waste (Moranda & Paladino, 2023).

Thermo-Chemical Recycling

Chemical recycling tends to tackle some of the problems confronted in mechanical recycling, such as problem of sorting as mixed plastics can be used as feed stock and produces a lesser amount of greenhouse gases as compared to thermal recycling (Ragaert *et al*., 2017; Vollmer *et al.*, 2020; Nikiema *et al*., 2022). Pyrolysis is one of the major thermochemical recycling processes. This process has proven to be the most efficient method of recycling waste plastic, as other methods still send the plastic back to the environment, therefore “postponing the evil days” (Geyer, 2020), whereas pyrolysis removes the waste plastic completely from the environment. Apart from confronting the challenge of plastic waste, it also resolves the challenge of the rapid need for fossil fuel (Pohjakallio *et al.*, 2020).

Pyrolysis involves the breaking down or degrading of long-chain polymers molecules of plastic into smaller and less complex molecules by the action of intense heat pressure and absence of air (Al-Rumaihi *et al*., 2022; Kabeyi *et al*., 2023). Study by Mibei *et al.* (2023) showed that the quality of the oil produced during pyrolysis is comparable to that of fossil fuel, which makes it suitable for diesel engine.

The yield of pyrolysis depends on some factors such as pressure, temperature, feed stock composition ratio, type of reactor, choice of catalyst, residence time, and particle size (Pohjakallio *et al*., 2020). According to Mibei *et al*. (2023), thermal pyrolysis produces oil paraffin, aromatic, isoalkanes and olefins, which are not suitable for combustion engins.

Catalysed pyrolysis enables the pyrolysis process to be carried out at a lower temperature than thermal pyrolysis, and lesser environmental pollutants including carbon (iv) oxide, water vapour are evolved since the reaction is done in an environment with absence of oxygen, fuel derived also contains a greater amount of octane number and lesser char (Czajczyńska *et al.*, 2017; Moranda & Paladino, 2023 Mibei *et al*., 2023). The composition of the feed stock also has a great effect on the product (Miandad *et al.*, 2019; Mibei *et al.*, 2023). Pyrolysis tends to require a lot of energy, therefore the use of a catalyst helps to reduce the temperature required, increase the rate of reaction, and ultimately reducing the long chain in products from the pyrolysis process, thereby reducing its boiling point (Thahir *et al.*, 2021; Mibei *et al.*, 2023). In recent times. Researchers have used low-cost catalyst such as fly ash, and red clay (Aisien *et al*., 2021; Mibei *et al.*, 2023). Other examples of catalyst are Fe_2O_3, $Ca(OH)_2$, natural zeolite, synthetic zeolite, and y-zeolite. (Miandad *et al.*, 2019; Aisien *et al*., 2021)

The liquid product from pyrolysis can be used for power generation, transportation fuel, heating and the gas product can be used for heating the raw materials for the pyrolysis process. (Miandad *et al.*, 2019; Aisien *et al*., 2021; Moranda & Paladino, 2023).

Establishing a chemical recycling facility is more expensive than a mechanical facility. According to Zheng *et al.* (2023), the estimation selling worth of products from chemical recycling, such as methanolysis and glycolysis is $0.96- 1.04 Kg, which is about twice the price of mechanical, recycled plastic, $0.54 kg. Therefore, efforts should be put in place to reduce the cost of chemical recycling.

INNOVATION ON PLASTIC MATERIALS- BIOPLASTICS

According to Kabasci, (2020) and European Bioplastic (EUBP) (2023a), bioplastics can be biodegradable, biobased or both. The biodegradable property of a plastic depends on the molecular structure of its polymer. Not all biobased plastics are biodegradable (Narancic *et al.*, 2020). An example is bio-polyethylene, which is non-biodegradable despite being derived from cane sugar while polycaprolactone, a fossil-based polymer is biodegradable (Kabasci, 2020).

Biobased plastics are plastics derived from biomass or non-fossilized and biodegradable organic materials gotten from animals, microorganisms and plants. Studies have shown that biodegradable plastics can be made from cane sugar, humbled masked bee, sea weeds, shrimps, avocado seeds, banana peels, rice, cassava (Censi *et al.*, 2022). Bioplastic made from starch is the most popular type of biodegradable plastic due to its low cost, avalability and its ability to degrade totally into environmentally friendly substances such as glucose. (Narancic *et al.*, 2020; Kabasci, 2020).

Global Production of Bio-plastics

The global production of bioplastics as of 2020 was estimated to be 2.11 million metric tons. This was forecasted to increase to 2.87 million metric tons by 2025. The largest market for bioplastics is the packaging industry with a production capacity of 555,000 metric tons. Asia is the world's largest producer of bioplastics with over 50% of the world's bioplastics (Statista, 2023). As reported by Statista (2021), BBCA Group, a Chinese Company, forecasted to increase its production of PLA from 50,000 tons by August 2020 to reach 700,000 tons annually by 2023, almost doubling the global demand for Polylactic acid (PLA) polymer (360,000 tons) for the year 2023 The use of PLA polymer that is the best substitute for PET (the most globally used type of plastic) is derived from corn and other plants presently used in producing drinking straws, apparel, bottles, medical devices, and nonwoven fabric masks. (Jiaming *et al.*, 2023)

Regulatory Frameworks for Single-use Bags and Bioplastics

Most countries are now aware of the problems associated with fossil-based plastics that have led to new legislations related to the use of single-use plastics and the replacement of fossil-based plastics with biobased plastics. Countries in Africa, such as Nigeria, Senegal, Tanzania, Madagascar, Mali, Morocco, and Kenya, already have legislation regulating the use of single-use plastics with Rwanda as the first African country to place a complete ban on all single-use plastics (Greenpeace Africa, 2020).

According to European Bioplastics (2023b), the European Union is putting a lot of effort into introducing regulatory frameworks, policies, and standards to improve bioeconomy in Europe that is beneficial to the bioplastic sector. Some of such policies, frameworks, and strategies are the EU Green Deal (2019), the Packaging & Packaging Waste Directive (review 2022), Policy Framework for biobased, biodegradable, and compostable plastics (2022). The People's Republic of China in 2020 introduced a ban on the importation, sale, use, and manufacture of non-biodegradable plastic bags (Arias, *et al.,* 2022; Bairong *et al*., 2023). However, there is a gap between public awareness and behavioural changes in most countries due to a lack of political will and the misconception that all biobased plastics are biodegradable (Moshood *et al.,* 2022)

The Pros and Cons of Bioplastics

Bioplastics have properties such as the ability to biodegrade within a short period into environmentally friendly products such as water and carbon(iv)oxide, thereby causing the environment no harm, low melt flow index, high impact strength, good elongation, anti-UV, anti-oxidation, and anti-moisture properties. Also, the production process of bioplastics emits a lesser carbon footprint compared to fossil-biased plastic (Greenhome, 2008; Jiaming *et al*., 2023). Bioplastics such as PLA and Polyhydroxybutyrate (PHB) are better for health. Therefore, suitable for producing food packaging materials.

However, the EU has recently raised concern about the degradability of biobased plastics in certain environments, as bioplastics are produced to degrade only in specific environments, such as soil in a marine environment (Havstad, 2020; European Bio-plastics, 2023). Studies have shown that bioplastics do not degrade in landfills, which is the final destination of most plastics (Folino, *et al*., 2020). Also, bioplastics are more expensive than fossil-based plastics, therefore increasing the cost of production of goods making products more expensive for the final consumer. Land used for cultivating crops competes with land for food production that might threaten food security and deforestation to grow crops for the feedstock of bioplatics. (Greenhome, 2008; Jiaming *et al*., 2023)

Therefore, a lot of issues remain unresolved regarding the use of bioplastics to tackle the current issue related to plastic pollution. Hence, facilitating an effective waste management system would be beneficial to the growth of the bioplastic industry. Also, bioplastics tend to leach harmful chemicals into the environment. Therefore, if not properly handled would be hazardous to the environment (Folino, *et al*., 2020).

Plastic Prohibition Policy in Nigeria: Lesson Learned from other Countries

The ban on the use of single-use plastic bags in Nigeria since 2019 has shown little or no effects on the behavioural and plastic management system in Nigeria, as the bill does not provide a holistic solution to the problem of plastic generation, management of plastic waste, public awareness and consultation but is just a punitive measure. Public awareness and education on environmental policy is essential and could result in voluntary initiatives. This has been effectively applied in countries like France, Finland, Luxembourg, and Indonesia. Also, the provision of a suitable, cost-effective, and accessible alternative to plastic single-use bags and the enforcement of plastic bag prohibition policies as used in countries like Morocco and Kenya would go a long way in tackling the problems of plastic pollution in Nigeria. The ban of plastic bags in Rwanda has shown positive impact on the environment, such as a reduction of flooding, erosion and harm to wildlife. The Nigerian Government can also look into the production and use of biobased biodegradable plastics as a lot of research has been done by academia on the use of cassava peels, an abundance of agricultural waste in Nigeria, for the manufacturing of bioplastics (Nwafor & Walker, 2020; Muposhi *et al*., 2022).

CONCLUSION

With the rapid increase in the demand and production of plastic, there is an urgent need to ensure that plastics are properly managed at their end of life. Researchers should concentrate on developing polymers that are easier to process at end-of-life and develop efficient methods for breaking plastics into valuable products. Technologies developed should look into tackling the environmental effects of the technology, such as minimizing energy, water, and toxic chemicals used. Also, technologies should be focused on developing cost-effective bioplastics that can biodegrade easily irrespective of environmental factors. In Nigeria, radical public awareness and advocacy should be done to ensure the reduction in the use of plastics, especially single-use plastic bags, and replacement of packaging materials with other eco-friendly materials. The production and commercialization of biobased plastics should be encouraged. Bioplastics must be properly managed by reducing, reusing, and recycling at their end of life. The Nigerian Government should also review the bill on the banning of single-use plastics to include public participation, public awareness, plastic waste generation and management. The scope of this review did not cover recycling of bioplastics and limited number of articles on the single-use plastic ban in Nigeria because of limited studies has been conducted in Nigeria.

REFERENCES

Adebiyi, F.M. (2022). Air quality and management in petroleum refining industry: A review. *Environmental Chemistry and Ecotoxicology*, 4, 89-96, https://doi.org/10.1016/j.enceco.2022.02.001.

Aisien, E.T, Otuya, I.C. & Aisien, F.A. (2021). Thermal and catalytic pyrolysis of waste polypropylene plastic using spent FCC catalyst. *Environmental Technology & Innovation,* 22, https://doi.org/10.1016/j.eti.2021.101455.

Akanyange, S.N, Zhang, Y, Zhao, X, Adom-Asamoah, G, Ature, A, Anning, C, Tianpeng, C, Zhao, H, Lyu, X. & Crittenden, J.C. (2022). A holistic assessment of microplastic ubiquitousness: Pathway for source identification in the environment. *Sustainable Production and Consumption* , 33, 113-145, https://doi.org/10.1016/j.spc.2022.06.020.

Alabi, O.A, Ologbonjaye, K.I, Awosolu, O. & Alalade, O.E. (2019). Public and Environmental Health Effects of Plastic Wastes Disposal: A Review. *J Toxicol Risk Assess,* 5:021, doi.org/10.23937/2572-4061.1510021

Arias, A, Feijoo, G.& Moreira, M.(2022).Technological feasibility and environmental assessment of polylactic acid-nisin-based active packaging, *Sustainable Materials and Technologies*, 33, https://doi.org/10.1016/j.susmat.2022.e00460.

Al-Rumaihi, A, Shahbaz, M, Mckay, G, Mackey, H. & Al-Ansari,T. (2022). A review of pyrolysis technologies and feedstock: A blending approach for plastic and biomass towards optimum biochar yield. *Renewable and Sustainable Energy Reviews*, 167, https://doi.org/10.1016/j.rser.2022.112715.

Bairong, W, Yong, L, & Xiaojing, C. (2023). The implementation effects of different plastic bag ban policies in China: the role of consumers' involvement. *Environ. Res. Commun,* 5(4), DOI 10.1088/2515-7620/accc11

Balwan, W, Singh, A.& Kour, S. (2022). 5R's of Zero Waste Management to save our green. planet: A Narrative review. *European Journal of Biotechnology and Bioscience,* 10: 1, 7-11, https://www.researchgate.net/publication/358221324_5R's_of_Zero_Waste_Management_to_save_our_green_planet_A_Narrative_review

Bujak, J.W. (2015). Thermal utilization (treatment) of plastic waste. *Energy*, 90(2), 1468- 1477, https://doi.org/10.1016/j.energy.2015.06.106.

Carneado, S., López-Sánchez, J.F. & Sahuquillo, Á. (2023). Antimony in Polyethylene Terephthalate-Bottled Beverages: The Migration Puzzle. Molecules, 28(20), https://doi.org/10.3390/molecules28207166

Censi, V, Saiano, F, Bongiorno, D, Indelicato, S, Napoli, A. & Piazzese, D. (2022). Bioplastics: A new analytical challenge. *Frontiers in Chemistry*,10, 10.3389/fchem.2022.971792

Cooper, R.G. & Harrison, A. (2009). The exposure to and health effects of antimony. *Indian Journal of Occupational and Environmental Medicine,* 13(1), 3-10, DOI:10.4103/0019- 5278.50716.

Czajczyńska, D.L, Anguilano, H, Ghazal, R., Krzyżyńska, A.J, Reynolds, N. & Jouhara, S. (2017). Potential of pyrolysis processes in the waste management sector. *Thermal Science and Engineering Progress,* 3, 171-197, https://doi.org/10.1016/j.tsep.2017.06.003.

Diana, Z.T, Virdin, J, Valiyaveettil, S, Li, H.X. & Rittschof, D. (2023). Editorial: Emerging challenges and solutions for plastic pollution. *Front. Mar. Sci.,* 10, doi: 10.3389/fmars.2023.1162680

European Bioplastics. (2023a). What are bioplastics? https://www.european-bioplastics.org/bioplastics/

European Bioplastics. (2023b). What regulatory framework is there for bioplastics on EU-level and what initiatives are underway? https://www.european-bioplastics.org/faq-items/what-regulatory-framework-is-there-for-bioplastics-on-eu-level-and-what-initiatives-are-underway/

European Commission. (2021). Guidance on Waste Definitions. file:///C:/Users/USER/Downloads/CPA%20Guidance%20Document%20on%20Waste%2 0(1).pdf

Folino, A, Karageorgiou, A, Calabrò, P.S. & Komilis, D. (2020). Biodegradation of Wasted Bioplastics in Natural and Industrial Environments: A Review. *Sustainability,* 12(15) https://doi.org/10.3390/su12156030

Genchi, G, Sinicropi, M.S, Lauria, G, Carocci, A. & Catalano, A. (2020). The Effects of Cadmium Toxicity. *Int J Environ Res Public Health*, 17(11), 3782, doi: 10.3390/ijerph17113782.

Geneva Environment Network. (2023). Plastics and the Environment. https://www.genevaenvironmentnetwork.org/resources/updates/plastics-and-the-environment/

Geyer , R, Jenna, R., Jambeck, & Law, K.L. (2017). Production, use, and fate of all plastics ever made. *Sci. Adv*., 3, DOI:10.1126/sciadv.1700782

Geyer, R. (2020). Production, use, and fate of synthetic polymers. In M.T, Letcher (Eds.), Plastic waste and recycling (pp 13-32). School of Chemistry, University of KwaZulu- Natal, Durban, South

Africa & Laurel House, Stratton on the Fosse, United Kingdom.

Greenhome. (2008). The Pros and Cons of Bioplastics. https://greenhome.co.za/the-pros-and-cons-of-bioplastics/

Greenpeace Africa. (2020). 34 Plastic Bans in Africa | A Reality Check. https://www.greenpeace.org/africa/en/blogs/11156/34-plastic-bans-in-africa/

Hahladakis, J.N, Velis, C.A, Weber, R, Iacovidou, E, Purnell, P. (2018). An overview of chemical additives presents in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. *Journal of Hazardous Materials*, 344 (15), 179-199, https://doi.org/10.1016/j.jhazmat.2017.10.014.

Harris, W. (2023). How Long Does It Take for Plastic to Decompose? https://science.howstuffworks.com/science-vs-myth/everyday-myths/how-long-does-it- take-for-plastics-to-biodegrade.htm

Havstad, M.R. (2020). Biodegradable plastics. In M.T, Letcher (Eds.), Plastic waste and recycling, (pp 97-129). School of Chemistry, University of KwaZulu-Natal, Durban, South Africa & Laurel House, Stratton on the Fosse, United Kingdom,

Jiaming, Y., Shengchao, X., Biao, L., Hailan, W., Fengmin, Q., Xiulian, R.& Qifeng, W. (2023). Bioplastic production: From monomer to the polymer. *European Polymer Journal,* 193, https://doi.org/10.1016/j.eurpolymj.2023.112076.

Kabasci, S. (2020). Biobased plastics, In M.T, Letcher (Eds.), Plastic waste and recycling (pp 67-96). School of Chemistry, University of KwaZulu-Natal, Durban, South Africa & Laurel House, Stratton on the Fosse, United Kingdom.

Kabeyi, M.J.B. & Olanrewaju,O.A.(2023). Review and Design Overview of Plastic Waste-to-Pyrolysis Oil Conversion with Implications on the Energy Transition. *Journal of Energy*, 2023, 25, https://doi.org/10.1155/2023/1821129

Kibria, M.G., Masuk, N.I., Safayet, R. et al. Plastic Waste: Challenges and Opportunities to Mitigate Pollution and Effective Management. *Int J Environ Res* , 20 (2023). https://doi.org/10.1007/s41742-023-00507-z

Kijo-Kleczkowska, A. & Gnatowski, A. (2022). Recycling of Plastic Waste, with Particular Emphasis on Thermal Methods—Review. *Energies,* 15(6), 2114, https://doi.org/10.3390/en15062114

Kilic, E. (2022). Microplastic ingestion evidence by economically important farmed fish species from Turkey. *Marine Pollution Bulletin*, 183(2), DOI:10.1016/j.marpolbul.2022.114097

Kökkılıç, O, Jam, S.M, Chu , P, Marion , C, Yang, Y. & Waters, K.E. (2022). Separation of plastic wastes using froth flotation – An overview. *Advances in Colloid and Interface Science*, 308, https://doi.org/10.1016/j.cis.2022.102769

Koongolla, J. B, Lin, L, Pan, Y.F, Yang, C.P, Sun, D.R, Liu, S. & Li, H.X. (2019). Occurrence of microplastics in gastrointestinal tracts and gills of fish from Beibu Gulf, South China Sea. *Environmental Pollution*, 113734. doi:10.1016/j.envpol.2019.113734

Letcher, M.T. (2020). Introduction to plastic waste and recycling. In M.T, Letcher (Eds.), Plastic waste and recycling (pp 3-12). School of Chemistry, University of KwaZulu-Natal, Durban, South Africa & Laurel House, Stratton on the Fosse, United Kingdom.

Li, W, Wang, S, Wufuer, R, Duo, J. & Pan, X. (2022). Microplastic Contamination in Urban, Farmland and Desert Environments along a Highway in Southern Xinjiang, China. *Int J Environ Res Public Health,* 19(15), doi: 10.3390/ijerph19158890.

Lin, X, Gowen, A.A, Pu, H. & Xu, J. Microplastic contamination in fish: Critical review and assessment of data quality. (2023). *Food Control*, 153, https://doi.org/10.1016/j.foodcont.2023.109939

Miandad, R, Rehan, M, Barakat, M.A, Aburiazaiza, A.S, Khan, H, Ismail, I.M, Dhavamani, J, Gardy, J, Hassanpour, A. & Nizami, A. (2019). Catalytic Pyrolysis of Plastic Waste: Moving Toward Pyrolysis Based Biorefineries. *Frontiers in Energy Research*, 7, 10.3389/fenrg.2019.00027

Mibei, Z.C, Kumar, A. & Talai, S.M. (2023). Catalytic Pyrolysis of Plastic Waste to Liquid Fuel Using Local Clay Catalyst. *Journal of Energy,* 11, https://doi.org/10.1155/2023/7862293.

Montserrat, F. (2020). Antimony and PET bottles: Checking facts. *Chemosphere* 261, https://doi.org/10.1016/j.chemosphere.2020.127732

Moranda, A. & Paladino, O. (2023). Controlled Combustion and Pyrolysis of Waste Plastics: A Comparison Based on Human Health Risk Assessment. *Recycling* , 8, 38, https://doi.org/10.3390/recycling8020038.

Moshood, T.D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M.H. & Ghani, A.A. (2022). Biodegradable plastic applications towards sustainability: A recent innovations in the green product. Cleaner Engineering and Technology, 6.

Muposhi, A, Mpinganjira, M. & Wait, M. (2022). Considerations, benefits and unintended consequences of banning plastic shopping bags for environmental sustainability: A systematic literature review. *Waste Manag Res.,* 40(3):248-261. doi: 10.1177/0734242X211003965

Oyen, A.V, Franeker, J.A , Oppermann, U, Egelkraut-Holtus, M. (2022).Heavy metals in plastic, recycling and environmental aspects. *Environmental and Geochemical Analysis,* 33,78.

Narancic, T, Cerrone, F, Beagan, N. & O'Connor, K.E. (2020). Recent Advances in Bioplastics: Application and Biodegradation. *Polymers (Basel),* 12(4), doi: 10.3390/polym12040920.

Nikiema, J. & Asiedu, Z. (2022). A review of the cost and effectiveness of solutions to address plastic pollution. *Environ Sci Pollut Res Int,* 29(17), 24547-24573. doi: 10.1007/s11356- 021-18038-5.

Nwafor, N.& Walker,T. (2020). Plastic Bags Prohibition Bill: A developing story of crass legalism aiming to reduce plastic marine pollution in Nigeria. *Marine Policy,* 120, https://doi.org/10.1016/j.marpol.2020.104160.

Oladele, I.O, Okoro, C.J, Taiwo, A.S, Onuh, L.N, Agbeboh, N.I, Balogun, O.P, Olubambi, P.A. & Lephuthing, S.S. (2023). Modern Trends in Recycling Waste Thermoplastics and Their Prospective Applications: A Review. *J. Compos. Sci.,* 7, 198. https://doi.org/10.3390/jcs7050198

Organization for Economic Cooperation and Development, OECD. (2022). Globally, only 9% of plastic waste is recycled while 22% is mismanaged. https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

Organization for Economic Cooperation and Development, OECD. (2023). Plastic leakage and greenhouse gas emissions are increasing. https://www.oecd.org/environment/plastics/increased-plastic-leakage-and-greenhousegasemissions.htm#:~:text=Throughout%20their%20lifecycle%2C%20plastics%20hav e,of% 20global%20greenhouse%20gas%20emissions.

Plastic oceans. (2022). Plastic pollution facts. https://plasticoceans.org/the-facts/

Pohjakallio, M, Vuorinen, T. & Oasmaa, A. (2020). Chemical routes for recycling—dissolving, catalytic, and thermochemical technologies, In M.T, Letcher (Eds.), Plastic waste and recycling (pp 359-384). School of Chemistry, University of KwaZulu-Natal, Durban, South Africa & Laurel House, Stratton on the Fosse, United Kingdom.

Ragaert, K., Delva, L. & Geem, K.V. (2017). Mechanical and chemical recycling of solid plastic waste. *Waste Management,* 69, 24–58, http://dx.doi.org/10.1016/j.wasman.2017.07.044

Riaza, S, Nasreena, Z, Burhana, S, Shafiquea, S. A, Alvib & Khanc, M.A. (2023). Microplastics assessment in Arabian Sea fishes: accumulation, characterization, and method development. *Brazilian Journal of Biology,* 84, https://doi.org/10.1590/1519-6984.270694

Rodriguez, F. (2023). plastic. Encyclopaedia Britannica. https://www.britannica.com/science/plastic

Saerens, A, Ghosh, M, Verdonck, J. & Godderis, L. (2019). Risk of Cancer for Workers Exposed to Antimony Compounds: A Systematic Review. *Int J Environ Res Public Health*, 16(22), doi: 10.3390/ijerph16224474.

Sarkingobir, Y, Bello, M, & Yabo, H.M. (2021). Harmful effects of plastics on air quality. *Academia Letters,* 2967, https://doi.org/10.20935/AL2967

Schyns, Z.O.G. & Shaver, P. M. (2021). Mechanical Recycling of Packaging Plastics: A Review. *Rapid Commun*., https://doi.org/10.1002/marc.202000415

Statista. (2023). Global bioplastics industry - statistics & facts. https://www.statista.com/topics/8744/bioplastics-industry-worldwide/

Statista, (2021). Production capacity of bioplastic types in China by selected manufacturing companies as of 2020. https://www.statista.com/statistics/1257460/bioplastic-production-capacity-of-selected-chinese-companies/

Takada, H. & Bell, L. (2021). Plastic Waste Management Hazards. *International Pollutants Elimination Network (IPEN)*, https://ipen.org/sites/default/files/documents/ipen- plastic- waste-management-hazards-en.pdf.

Thahir, R, Irwan, M, Alwathan, A. & Ramli, R. (2021). Effect of temperature on the pyrolysis of plastic waste using zeolite ZSM-5 using a refinery distillation bubble cap plate column. *Results in Engineering*, 11, https://doi.org/10.1016/j.rineng.2021.100231.

The Gaurdian. (2017). 38 million pieces of plastic waste found on uninhabited South Pacific island. https://www.theguardian.com/environment/2017/may/15/38-million-pieces-of- plastic-waste-found-on-uninhabited-south-pacific-island.

Thompson, R.C, Moore, C.J, Vom Saal, F.S, Swan, S.H. (2009). Plastics, the environment and human health: current consensus and future trends. *Philos Trans R Soc Lond B Biol Sci,*364(1526), 2153-66, doi: 10.1098/rstb.2009.0053.

United Nations Environmental Programme. (2022). Plastics Leaching into Farmer's Fields at alarming rate: news report. https://www.unep.org/news-and-stories/story/plastic-leaching-farmers-fields-alarming-rate-new-report#:~:text=These%20microplastics%20can%20change%20the,and%20lead%20to%20health%20implications.

United Nations Environmental Programme, UNEP. (2023). Our planet is chocking on Plastics. https://www.unep.org/interactives/beat-plastic-pollution/

United Nations, (2021). In Images: Plastic Is Forever. Https://Www.Un.Org/En/Exhibits/Exhibit/In-Images-Plastic-Forever

Verma, R, Vinoda, K.S, Papireddy, M. & Gowda, A.N.S . (2016). Toxic Pollutants from Plastic Waste- A Review. *Procedia Environmental Sciences,* 35, 701 – 708, http://dx.doi.org/10.1016/j.proenv.2016.07.069

Vollmer, I, Jenks, M.J.F, Roelands, M.C.P, White, R.J, van, H.T, de Wild, P, van der Laan G.P, Meirer, F, Keurentjes, J.T.F. & Weckhuysen, B.M. (2020). Beyond Mechanical Recycling: Giving New Life to Plastic Waste. *Angew Chem Int Ed Engl,* 59(36), 15402- 15423, doi: 10.1002/anie.201915651.

World Health Organization, WHO. (2023). Lead poisoning. https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and health#:~:text=Lead%20also%20causes%20long%2Dterm,birth%20and%20low%20birth %20weight.

Zheng, J, Arifuzzaman, M, Tang, X, Chen, X.T. & Saito, T. (2023). Recent development of end-of-life strategies for plastic in industry and academia: bridging their gap for future deployment. *Mater. Horiz.,* 10, 1608–1624.