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COST-BENEFIT ANALYSIS OF PLASTIC WASTE MITIGATION STRATEGIES IN UGHELLI, DELTA STATE, NIGERIA

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ABSTRACT: *Global plastics waste is an issue of ever-increasing urgency. Marine plastic pollution is a particularly challenging issue, as plastics take decades to break down, and so do micro- and nanoparticles that affect marine ecosystems and the food web. The plastics pollution problem is magnified in developing countries where rising production and consumption coexist with underdeveloped waste treatment systems and large volumes of imported plastic waste. Plastic waste management has become a critical environmental and public health challenge in many developing countries and cities, including Ughelli in Delta State, Nigeria. This study presents a comprehensive cost-benefit analysis of four key plastic waste mitigation strategies namely, a household waste segregation program, a plastic waste collection and recycling system, public awareness campaigns, and a deposit-refund scheme for plastic bottles and containers for implementation in Ughelli. Using a 0.5-year project timeframe and a 10% discount rate, the net present value (NPV) and cost-benefit ratios were calculated for each strategy. The results indicate that the plastic waste collection and recycling system had the highest NPV of ₦112,500,000 and a cost-benefit ratio of 1.50, suggesting it is the most financially viable option. The household waste segregation program had an NPV of ₦80,000,000 and a cost-benefit ratio of 1.35, also demonstrating strong economic feasibility. The public awareness campaigns and deposit-refund scheme had lower but still positive NPV values of ₦52,500,000 and ₦25,000,000 respectively, with cost-benefit ratios of 1.28 and 1.08. These findings provide valuable insights to policymakers and waste management authorities in Ughelli on prioritizing investments in sustainable plastic waste mitigation based on financial and economic considerations. It recommends greater external financial and technical support for waste treatment, stakeholder consensus and awareness-building, regulatory policies that reduce the price and convenience differentials between plastics and substitute materials, and a push towards enforcement of environmental regulations.*

KEYWORDS: Plastics, Waste, Mitigation Strategies. Cost-Benefit Ratio, Ughelli, Plastics, Waste, Environment, Manufacturing, Pollution, Biodegradable plastics, Plastic substitutes.

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INTRODUCTION

Plastics are synthetic materials made from polymers, which are long chains of molecules created through the polymerization of monomers. Plastics are categorized into several types based on their chemical composition and physical properties, Plastics are primarily composed of binders, fillers, pigments, plasticizers, and other additives. Plastics are categorized into thermoplastics and thermosets based on their physical and chemical properties. Thermoplastics are the class of plastics that can be melted and molded by heating and hardened by cooling. They can be reheated, reshaped, and hardened repeatedly. Polyethylene (PE), Polystyrene (PS), Polyvinyl Chloride (PVC), Polyethylene Terephthalate (PET), Polymethyl Methacrylate (PMMA). Polyethylene is widely used in the production of plastic materials. Polyethylene is resistant to acids, water, alkali, and most organic solvents. These plastic qualities also make them mechanically recyclable, which is a good method of waste management (Ronca, 2017). Polyethylene (PE) is the most widely used plastic, found in products like shopping bags, bottles, and packaging (Shen et al., 2010). Polyethylene (PE) is known for its toughness and resistance to chemical solvents and it is used in automotive parts, household goods, and textiles (Andrady, 2015). Polyvinyl Chloride (PVC) is commonly used in pipes, medical equipment, and flooring. It is valued for its durability and resistance to environmental degradation (Reiser, 2018). Polystyrene (PS) is used in disposable cutlery, CD cases, and insulation and can be found in both rigid and foam forms (Hopewell et al., 2009). Polyethylene Terephthalate (PET) is frequently used in beverage bottles and food containers, PET is known for its strength and clarity (Puckett, 2010). Polymethyl Methacrylate (PMMA) is often used as an alternative to glass in applications like lenses, displays, and signs due to its clarity and weather resistance (Averous & Boquillon, 2004). The remarkable physical and chemical characteristics of plastics, they are prized for their versatility, durability, and low cost making them a major commodity worldwide with several applications in commercial and industrial products, making them ubiquitous in modern life. As a result of high community demand, there is large-scale production of plastics worldwide (Frienkel, 2011). However, the use of plastics comes with many harmful environmental impacts related to their production and poor methods of waste treatment. Around 9% of the generated wastes were recycled, which was a very minute quantity compared to total production (Evode et al., 2021). Approximately 80% of the generated wastes were reported to accumulate in landfills or in the natural environment (Gourmelon, 2015). Under different circumstances, ultraviolet light can decompose plastics into their monomeric constituents, which are highly complicated and almost impossible to recover, disrupting food chains and disturbing human and environmental health (Li et al., 2021; Asgher et al., 2020). About 40% of plastic materials worldwide are used to stock and package finished products from different factories. Plastics had a significant contribution in creating a sustainable, proper, hygienic, cost-effective, energy-efficient, and environmentally friendly packaging system that can keep the environment clean (Zhao et al., 2021). The versatility of plastics has provided an efficient proof of hygienic and cost-effective packaging of food products like bread, rice, snacks, juices, spices, milk, edible oil, wheat flour, and confectioneries, and various types of pharmaceutical products resulting too increasingly high applications and generating huge post-utilization waste burden on the environment.

The rapid increase in plastic production over recent decades has created significant environmental challenges, particularly in developing countries like Nigeria and in urban areas like Ughelli, Delta State, Nigeria. The global production and use of plastics has surged

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dramatically, reflecting the material's versatile applications and cost-effectiveness. The global and Nigerian plastics production is presented in Table 1. This table provides a comparative snapshot of plastics production on a global scale versus Nigeria, helping to contextualize the scale of the issue in both broader and local terms.

Table 1: Global and Nigerian Plastics Production Data

Region/Country	Plastics Production (Million Metric Tons|)	Year
Global	367	2020
Nigeria*		2020

* Data for Nigeria is an estimate based on industry reports and local production statistics.

In 2020 alone, the world produced approximately 367 million metric tons of plastic (Geyer, Jambeck, & Law, 2017) and are employed in numerous sectors including packaging, construction, and consumer goods, due to their durability, lightweight nature, and affordability. This widespread use has led to an accumulation of plastic waste that far exceeds the capacity of existing waste management systems (Plastics Europe, 2021). The environmental and economic impacts of this massive plastic production are profound. Plastics' durability, while beneficial for many applications, means that once discarded, they persist in the environment for centuries. This persistence contributes to widespread pollution, affecting land, waterways, and marine environments (Jambeck et al., 2015). Plastic waste is often found littering streets and clogging drainage systems, leading to severe environmental degradation and increased public health risks (Ikpefan & Agbazue, 2021).

Millions of tons of plastic are consumed annually in the world due to its significant characteristics such as durability, flexibility, and low weight. High consumption has made plastic one of the most important municipal solid waste compounds, the quantity of which has increased in recent decades. In Nigeria, the proliferation of plastic products mirrors global trends. The country's burgeoning population and growing urbanization have exacerbated the problem, with plastics becoming a dominant component of municipal solid waste (Ogunseitan, 2018). The production of plastics in Nigeria is driven by local demand and a relatively unregulated industrial sector, resulting in high volumes of plastic waste being generated in urban areas like Ughelli (Nkwachukwu et al., 2013). The environmental and economic impacts of this massive plastic production are profound. Plastics' durability, while beneficial for many applications, means that once discarded, they persist in the environment for centuries. This persistence contributes to widespread.

Harmful Effects of Plastic Wastes

The physicochemical properties of plastics contribute to their usefulness, and their wastes after utilization have thrown away their durability advantage, which supports their usefulness and wastes after utilization (Vanapalli et al., 2021), Plastic solid wastes are known as a threat to the environment. Some of the harmful effects which the poor management of plastics can cause the environment and man after utilization include a series of environmental hazards to safety and choking of the drains in urban cities and other production areas as a result of its non-biodegradability and poor waste management practices (Gu, 2021). The municipal solid waste counted under 10%–12% of the plastic residue is combusted. After the combustion process, the gasses are released into the environment, which increases air pollution and

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causes greenhouse effects. The substances released in the atmosphere are furans, mercury, dioxins, and polychlorinated biphenyls. Immediate measures and implementations are needed to address and manage them properly, which can protect the environment. This is also applied in an aqueous environment for aquatic and aquaculture protection since many of these contaminants are hydrophobic, plastic in the aquatic environment is potentially acting as a sink for contaminants which make them less accessible to wildlife, particularly if they are buried on the seafloor (Abdul–Latif et al., 2021), The poor disposal and plastic waste mistreatment effects are categorized under three main classes, including the effects of plastic waste on animals, public health, and environmental pollution. Fig. 1 provides an illustration of the fate of plastic materials with harmful impacts on the ecosystem (Ali et al., 2021).

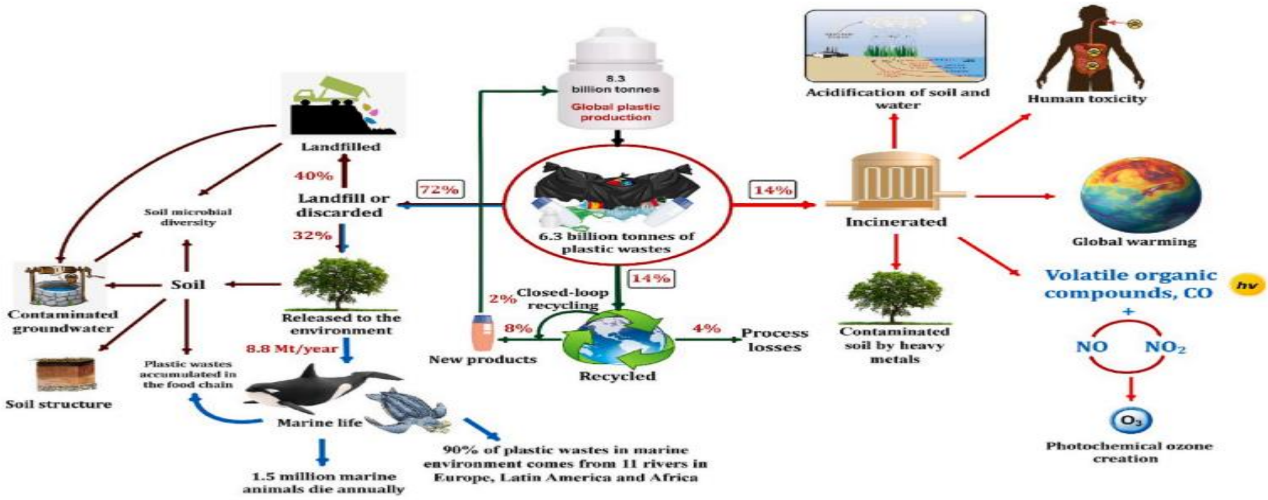

Figure 1: Illustration of the fate of plastic materials with harmful impacts on the ecosystem (Ali et al., 2021).

Management Strategies for Plastic Wastes

The best mitigation strategies are reduce, reuse and recycle. The most effective way to reduce waste is to not create it in the first place, so focus on reducing your waste as much as possible. Instead of discarding unwanted plastic items that are still in good shape, try selling or donating them, so others can reuse them. Plastic wastes are rapidly produced and exposed at a high rate due to the world's industrial development and population growth. Both biodegradable and non-degradable wastes are highly generated from man-made activities (operational sectors and climatic conditions, industrial growth, socio-economic development) and the natural processes of living creatures. Government municipalities, social communities, and local authorities have established different measures and environmental safety legislation rules that can guide the population to dispose of plastic waste after utilization (Benson et al., 2021). The efficient management in various aspects such as cost–benefit requires decision-making tools. Plastics are useful in daily life in different communities, its post-use can change different parameters of the world if not well managed. Some of these effects could be harmful to the environment, including human beings. Therefore the need to proffer effective plastic waste management strategies can not be emphasized enough, In these waste management strategies, several are scientifically based, such as recycling, incineration, bioremediation, and landfills. These methods are established to have a clean environment and good plastic waste disposal (David & Joel, 2018). These include:

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a. Recycling: Recycle all of the plastic you can in your life. Recycling refers to the waste management method which collects waste materials and converts them into raw materials that can be reused to form other valuable products. It is also known as "renewing or reusing" to prevent the harmful effect on society and environmental protection. The plastics are non-biodegradable as carbon-based products and other polymers. It contains bottles and other materials that can be melted and transformed into other products like plastic tables and chairs. This process is performed in the following six steps: collecting waste plastics, sorting, or arranging plastics into categories, washing to remove impurities, shredding and resizing, identifying and separating plastics, and compounding (Szostak et al., 2021). There are several benefits of plastic waste recycling that the world can gain when plastic are reused rather than disposing of them in non-desirable places, one of the advantages is the protection of human life by decreasing carbon dioxide and other harmful gasses in the atmosphere, which can occur during incineration or combustion of the wastes (Vollmer, et al., 2020). Recycling reduces pollution across the ecosystem, requires less energy, and helps in natural conservation. It saves fast-depleting landfill space and eases the demand for fossil fuel consumption. Moreover, it promotes a sustainable lifestyle and contributes to the national economy. Although recycling has different benefits to the community, it also has some disadvantages that can be managed and controlled. During the recycling process, some chemicals are released into the environment. Among these chemicals, some are volatile gasses that come from plastic waste compositions and organic chain of monomers that build up a plastic chain of organic fumes and ashes, which kill plant structure and affect wildlife when inhaled by different animals that live near the recycling zone. As the process requires heat to melt plastics, it also generates sulfur, carbon, and other gasses emitted to the environment. These gasses can cause global warming, greenhouse effect, and acidic rain that harm the environment in different ways (Shen & Worrell, 2014). This can also lead to health issues for the population who are crossing the plastics recycling zone. After the plastics downcycling process, wastes are separated for continuous recycling, which explains how it ends up with plastic that is generally unfit for another round of recycling. This means that it ends up in a landfill rather than regarding them as a secondary use of unconsumed plastic waste. (Zheng et al., 2005).

b. Incineration: The waste incineration method refers to the burning of wastes in oxygen, which is chemically known as complete combustion that releases water molecules and carbon dioxide into the atmosphere (Shome, 2020). The waste produced after incineration is composed of different volatile chemicals, ash, and a small amount of hydrochloric acid. Generally, all plastic waste is not a good candidate for combustion; some are resistant to oxygen heating and explosives. It is not an obligation that incineration can be used to treat all household waste plastic types properly. To select plastics to be incinerated, we must be careful on non-combustible waste to avoid these unprepared explosive accidents. The combustion of organic molecules can also produce energy which is known as fuel. The fuels can be presented in different physical states like liquid, solid, and gas used by vehicles and airplane propulsion. This method of incineration has several different positive impacts on society rather than energy production. It also has huge contributions in minimizing waste and producing electricity from the waste, which is highly needed in modern industrialization (De Weerdt, 2020. Waste incineration has played a critical part in producing renewable energy from biomass resources. Incineration, including heat recovery, was used in a different part of the world and more than four hundred fifty times in Europe (European Commission, EC, 2013). Despite the decreasing waste generated from different factories and other production

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houses, each person in the European Union generally generates 481 kg of municipal waste. There are several benefits of plastic waste management through incineration. These include decreased quantity of waste in the ecosystem, produce heat and power needed in different activities, reduces pollution of the atmosphere, saves economy on transport fee of the waste, and emilites harmful germs and chemicals. Moreover, it can be applied in any season or weather and prevents the production of methane gas. Incineration as a chemical process has benefits and drawbacks like all other biochemical processes or scientific processes. Some of the disadvantages of the incineration process include expensive setup compared to other waste management methods. It pollutes the environment and can damage public health. It releases ash waste that can harm people and the environment (Netzer et al., 2021)

c. Landfills: Plastics disposal post-utilization in different dustbins ends-up in landfill. Through this manual disposal process, many precautionary measures should be applied to avoid secondary side effects like groundwater contaminants and soil degradation that can result from poor processing (Zheng et al., 2005). The objectives of landfill arrangement are to provide a safer area of plastic waste disposal to protect all dimensions of the environment, i.e., aquatics and airspace, to achieve the objectives mentioned above. It demands a lot of work be done in the community, like digging a long hole or dumping in high depths and putting waste into it and letting it decompose. This process is completed very slowly, as it can take more than a year (Liang et al., 2021). During this landfill's processing, each organic molecule passes through biodegradation and decomposition. Plastic bags and other long polymer wastes can take around ten to a hundred years to degrade in landfills processing (Thiounn & Smith, 2020). Different plastic wastes can take a long time of degradation due to their specific biochemical properties and environmental or climate conditions like sunlight, wind, and climate change without these main driving factors (Zhou, 2014). Landfills are an excellent energy source due to the carbon dioxide and methane gas produced during the biodegradation process. It keeps cities clean, hygiene maintenance and segregates hazardous waste from other types of wastes. Moreover, this is a cost-effective method of plastic waste management. Although this method can be used to treat plastics wastes, it has some disadvantages, including being partially responsible for climate change and lighting up methane as combustible gas. It contaminates soil and water and affects wildlife (Kedzierski et al., 2020).

d. Pyrolysis: Pyrolysis refers to the process of converting gasses and fatty oils to recover crude petrochemicals and obtain hydrocarbons. It is even used to recover crude petrochemicals and generate renewable energy from plastic wastes (Sharuddin, et al., 2016). Pyrolysis process is classified into three main categories according to the amount of heat energy needed to destroy plastic connections. There is high temperature, medium temperature, and low temperature-based media. The products resulting from the pyrolysis of plastics, depending on different factors like reactor type, residence time, plastics, condensation arrangement, feeding arrangement, and the temperature applied (Miandad et al., 2016; Qureshi et al., 2020). This scientific method is an efficient manner of waste management even though it may require high capital cost (Sharuddin et al.,2016).

e. Bioremediation: It refers to the process where microorganisms decompose wastes (Asgher et al., 2021; Xu, et al., 2021). It needs different conditions for culture medium like nutrients, enzymes, pressure, and temperature, which all need to be settled at an optimum level to facilitate the growth of microorganisms. In the absence of any of the mentioned factors or the

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presence of growth inhibitors, the bioremediation process will not be well applied (Asgher et al., 2020).

Cost Benefit Analysis (CBA)

Cost benefit analysis is a method for measuring, in financial terms, the costs and benefits of an investment project. It includes a consideration of the external costs and benefits to society as well as the costs and benefits to just the business. Cost benefit analysis is often used by governments when they are considering a public project, such as the building of a new motorway, rail bridge or hospital, waste management strategies etc. Many different options can be ranked in order. When carrying out a cost benefit analysis there are a wide range and variety of costs and benefits to be identified and given a value. These can be divided into two groups:

i. Private Costs and Benefits: Private Costs are costs that the business making the investment must accept. They include training and recruitment costs, the purchase of new capital equipment and marketing costs, among others. Private Benefits are benefits that the business gains from as a result of making the investment. These benefits will include things such as increased productivity, increased sales, brand values and increased profits.

ii. Public Costs and Benefits: These are benefits external to the business that result from making the investment. An obvious external benefit from a large-scale investment would be jobs created by the business. Other public benefits include further jobs created outside the business as a result of increased business activity and an increase in tax paid by employees to the government. In areas where unemployment is high, crime and social problems might be reduced. These could include a building company that will have an environmental impact as it builds houses – increased traffic, noise etc. A farm extracting water from a river to irrigate its crops leaves less water further downstream for fishing. A new factory may involve the loss of open space, increased traffic congestion and so on.

Social Costs and Benefits: Social Benefit (private benefit + public benefits) – Social Cost (private costs + public costs). If the social benefits are greater than social costs, then go ahead with the proposal. If the social costs are greater than social benefits, then do not go ahead with the proposal.

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MATERIALS AND METHODS

Study Area

Ughelli is the administrative headquarter of Ughelli North Local Area of Delta State. It is situated in the central part of Delta state and located between Latitude 5^0 28^1 39.0^{11}N and 5^0 58^1 301.5^{11}E and longitude 5^0 30^1 53^{11}N and 6^0 01' 04.5" E (Rume, 2023). It covers an area of about 20 km^2 and has a population of about 350,000. Ughelli has several schools, markets, a general hospital, lots of private hospitals/clinics and a local government secretariat. The city is a link between Delta North and Delta South. Its centrality makes it a major commercial hub with lots of markets, schools and medical facilities. Ughelli is located in close proximity to the floodplains of the West Niger Delta river and is surrounded by neighboring communities and villages. Among these are Agbara-Otor, Agbaro, Ufuoma, Otokutu, Ogor. · The city has crude oil and gas reserves hence the presence of Shell Petroleum Development Company (SPDC). The site is part of a low-lying plain with land elevation generally under 50 m above mean sea level (Aweto, 2002), and with no marked imposing hills that rise above the general land surface. The climate is humid subequatorial with a long wet season. which lasts from March to October, alternating with a shorter dry season that lasts from November to February. The study area is shown in Figure 2.

The annual temperature ranges from 20^{o}C to 34^{o}C; with average values of 27^{o}C and are usually higher during the day and lower at night. Relative humidity varies between 55% and 75% throughout the year. Vegetation of the area is typical of tropical rain forest regions, which have been subjected to suffering quantum deforestation emanating from urbanization, sand dredging, farming and exploration and exploitation of oil and gas activities.

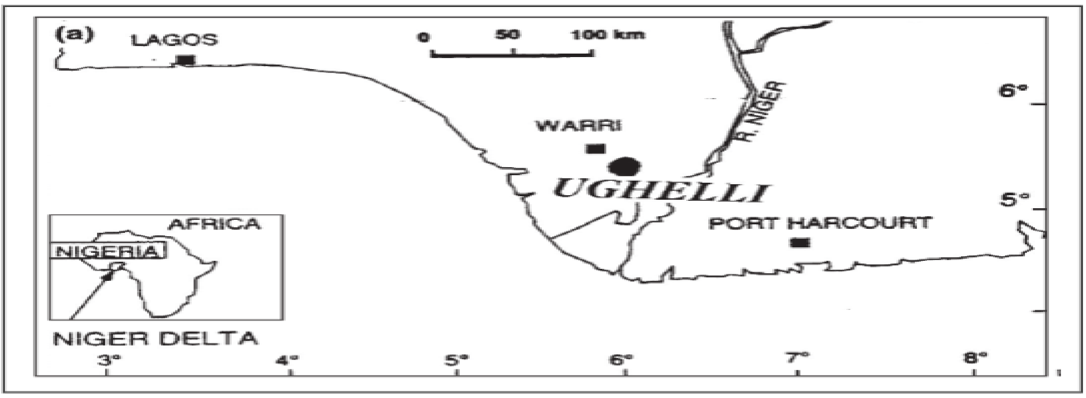

Figure 2: Map of Ughelli Showing the Study Area

Materials

To ensure the efficient and accurate collection, processing, and analysis of the data required for the study on plastic waste management in Ughelli, the following materials were used:

i. Waste Collection Bags: Pre-labeled waste collection bags in different colors (e.g., green for organic waste, blue for paper, yellow for plastic) were distributed to the sampled households for the waste characterization exercise.

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ii. Weighing Scales: Calibrated digital weighing scales with a capacity of up to 50 kg were used to measure the weight of the collected waste samples.

iii. Sorting and Categorization Equipment: Tables, trays, and sorting bins were used to manually sort and categorize the plastic waste components by type and item.

iv. Personal Protective Equipment (PPE): Gloves, facemasks, and safety goggles were used to ensure safety during the waste handling and sorting activities.

v. Tablets/Smart phones: Handheld devices were used to record field observations, conduct interviews, and capture photographic evidence during the data collection process.

vi. Stationery: Notebooks, pens, markers, and clipboards were used for note-taking, labeling, and documentation purposes.

vii. Cameras: Digital cameras were used to document the waste management practices, waste composition, and environmental impacts observed during the field visits.

viii. Spreadsheet Software: Microsoft Excel or a similar spreadsheet program was used for data entry, analysis, and the creation of tables and graphs.

Methods

Given the challenges arising from plastic waste, it is crucial to assess the effectiveness of various plastic waste mitigation strategies through a cost-benefit analysis. This analysis will help determine the most efficient and sustainable approaches for managing plastic waste considering both economic and environmental factors. By evaluating the costs of implementing these strategies against their benefits, this study aims to provide valuable insights into optimizing plastic waste management practices in the context of rising plastic production. This was achieved as follows:

Sampling and Data Collection

a) Household Waste Characterization

A representative sample of 500 households was selected from different residential areas in Ughelli using a stratified random sampling approach. The households were provided with pre-labeled waste collection bags and instructed to segregate their waste into different categories, including plastic, organic, paper, and other waste, for a period of 90 consecutive days. The collected waste samples were weighed, and the plastic waste component was further sorted and categorized by type (e.g., polyethylene, polypropylene, polyethylene terephthalate) and item (e.g., bottles, bags, packaging). This allowed for the determination of the composition and generation rates of plastic waste at the household level.

b) Commercial and Institutional Waste Assessment

To capture the plastic waste generated from commercial and institutional sources, a survey was conducted among 100 businesses and 50 public institutions (e.g., government offices, schools, hospitals) in Ughelli. The participants were asked to provide estimates of their weekly plastic waste generation and the types of plastic items commonly disposed of.

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Additionally, direct observations and spot-checks were carried out at 20 randomly selected commercial and institutional establishments to validate the self-reported data and obtain more accurate measurements of plastic waste generation.

c) Waste Collection and Disposal Practices

Information on the existing solid waste management system in Ughelli was collected through interviews with the local government authorities, waste management service providers, and informal waste collectors. Data was gathered on the coverage and frequency of waste collection, disposal methods (e.g., landfilling, open dumping, burning), and the challenges faced in managing plastic waste.

d) Data Analysis

Plastic Waste Quantification

The data collected from the household waste characterization and commercial/institutional surveys was used to estimate the total plastic waste generation in Ughelli. The average plastic waste generation per capita was calculated, and the total plastic waste generation was extrapolated based on the town's population of approximately 350,000 residents. This was achieved through the following quantification process.

i. Calculated the average plastic waste generation per household and per commercial/institutional establishment based on the primary data collected.

ii. Extrapolated the total plastic waste generation from households and commercial/institutional sources by multiplying the average values with the total number of entities.

iii. Aggregated the household and commercial/institutional plastic waste generation to obtain the total plastic waste generation in Ughelli.

iv. Divided the total plastic waste generation by the total population to determine the per capita plastic waste generation rate.

Cost-Benefit Analysis

A cost-benefit analysis was conducted to evaluate the feasibility of potential plastic waste mitigation strategies adopted. These included improved waste collection, recycling, and awareness campaigns. This analysis considered the estimated capital and operational costs, as well as the potential environmental, social, and economic benefits of each intervention. The cost-benefit analysis for the plastic waste mitigation strategies in Ughelli was performed using the following steps:

a. Identification of Mitigation Strategies: The research team identified a set of potential plastic waste mitigation strategies, which included implementing a household waste segregation program, establishing a plastic waste collection and recycling system, promoting public awareness campaigns on proper waste management and developing a deposit-refund scheme for plastic bottles and containers.

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b. Quantification of Costs: For each mitigation strategy, the following cost components were estimated:

capital costs (equipment, infrastructure), operational costs (labor, transportation, processing)

administrative and management costs, and monitoring and evaluation costs.

c. Quantification of Benefits: The potential benefits of implementing the mitigation strategies were quantified, which included reduced plastic waste disposed of in landfills or the environment, increased plastic waste recycling and resource recovery, improved public health and environmental conditions, job creation and income generation opportunities and reduced cleanup and waste management costs for the local government.

d. Net Present Value (NPV) Calculation: The researchers calculated the NPV for each mitigation strategy over a 0.5year time horizon, using an appropriate discount rate (8-10%) and The NPV formula.

$$NPV = \frac{\sum(Benefits - Costs)}{(1 + Discount\ )^t} \qquad (1)$$

Where t represents the time period (year) an the discount rate accounts for the time value of money.

e. Cost-Benefit Ratio Calculation: *For each mitigation strategy, the researchers calculated the cost-benefit ratio by dividing the total discounted benefits by the total discounted costs.*

$$Cost - Benefit\ Ratio\ = \frac{\left(\frac{\sum B}{(1 + Discount\ )^t}\right)}{\left(\frac{\sum C}{(1 + Discount\ )^t}\right)} = \frac{Total\ Discounted\ Benefit}{Total\ Disounted\ Cost} \qquad (2)$$

Project duration (t) = 0.5 years (6 months)

Discount rate (r) = 10% per annum

Household Waste Segregation Program

Initial Investment (I) = ₦60,000,000

Annual Benefits (B) = ₦80,000,000

Annual Costs (C) = ₦40,000,000

$$NPV = \frac{\sum(₦80{,}000{,}000\ -\ ₦40{,}000{,}000)}{(1\ +\ 0.1)^{0.5} - ₦60{,}000{,}000} = ₦80{,}000{,}000$$

$$Cost - Benefit\ Ratio\ = \frac{\left(\frac{\sum B}{(1 + Discount\ )^t}\right)}{\left(\frac{\sum C}{(1 + Discount\ )^t}\right)} = \frac{Total\ Discounted\ Benefit}{Total\ Disounted\ Cost}$$

$$Cost\text{-}Benefit\ Ratio = \frac{\left(\frac{\sum ₦80{,}000{,}000}{1.049}\right)}{\left(\frac{\sum ₦40{,}000{,}000}{1.049}\right)} = 1.35 \qquad (2)$$

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Project duration (t) = 0.5 years (6 months)

Discount rate (r) = 10% per annum

Household Waste Segregation Program

Initial Investment (I) = ₦60,000,000

Annual Benefits (B) = ₦80,000,000

Annual Costs (C) = ₦40,000,000

$$NPV = \frac{\sum(₦100,000,000 - ₦50,000,000)}{(1+0.1)^{0.5} - ₦75,000,000} = ₦112,500,000$$

$$\textit{Cost-Benefit Ratio} = \frac{\left(\frac{\sum B₦100,000,000}{1.049}\right)}{\left(\frac{\sum ₦50,000,000}{1.049}\right)} = 1.50$$

Public Awareness Campaigns

Initial Investment (I) = ₦40,000,000

Annual Benefits (B) = ₦60,000,000

Annual Costs (C) = ₦40,000,000

$$NPV = \frac{\sum(₦60,000,000 - ₦40,000,000)}{(1+0.1)^{0.5} - ₦40,000,000} = ₦52,500,000$$

$$\textit{Cost-Benefit Ratio} = \frac{\left(\frac{\sum ₦60,000,000}{1.049}\right)}{\left(\frac{\sum ₦40,000,000}{1.049}\right)} = 1.28$$

Plastic Waste Collection and Recycling System

Initial Investment (I) = ₦75,000,000

Annual Benefits (B) = ₦100,000,000

Annual Costs (C) = ₦50,000,000

$$NPV = \frac{\sum(₦100,000,000 - ₦50,000,000)}{(1+0.1)^{0.5} - ₦75,000,000} = ₦112,500,000$$

$$\textit{Cost-Benefit Ratio} = \frac{\left(\frac{\sum B₦100,000,000}{1.049}\right)}{\left(\frac{\sum ₦50,000,000}{1.049}\right)} = 1.50$$

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Public Awareness Campaigns

Initial Investment (I) = ₦40,000,000

Annual Benefits (B) = ₦60,000,000

Annual Costs (C) = ₦40,000,000

$$NPV = \frac{\sum(₦60,000,000 - ₦40,000,000)}{(1 + 0.1)^{0.5} - ₦40,000,000} = ₦52,500,000$$

$$\textit{Cost-Benefit Ratio} = \frac{\left(\frac{\sum ₦60,000,000}{1.049}\right)}{\left(\frac{\sum ₦40,000,000}{1.049}\right)} = 1.28$$

Deposit-Refund Scheme for Plastic Bottles and Containers

Initial Investment (I) = ₦20,000,000

Annual Benefits (B) = ₦30,000,000

Annual Costs (C) = ₦25,000,000

$$NPV = \frac{\sum(₦30,000,000 - ₦25,000,000)}{(1 + 0.1)^{0.5} - ₦25,000,000} = ₦25,000,000$$

$$\textit{Cost-Benefit Ratio} = \frac{\left(\frac{\sum ₦30,000,000}{1.049}\right)}{\left(\frac{\sum ₦25,000,000}{1.049}\right)} = 1.08$$

e. Sensitivity Analysis

Sensitivity analyses were conducted to assess the robustness of the cost-benefit results, by varying key input parameters (discount rate, cost estimates, benefit projections) and observing the impact on the NPV and cost-benefit ratio.

f. Recommendation and Prioritization

Based on the NPV and cost-benefit ratio analyses, the researchers prioritized the mitigation strategies and provided recommendations to the local government on the most viable and impactful options to implement.

The cost-benefit analysis approach allowed the research team to compare the relative merits of different plastic waste mitigation strategies and make evidence-based recommendations to the Ughelli authorities on the most effective and financially sustainable interventions to pursue. The findings from the data collection and analysis were used to develop a set of context-appropriate recommendations for improving plastic waste management in Ughelli, which are presented in the subsequent sections of the report.

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RESULTS AND DISCUSSIONS

i. Plastic Waste Generation and Composition

The study found that the total plastic waste generation in Ughelli, Delta State, Nigeria, is approximately 158,195 kg per year. This includes 136,875 kg/year from household sources and 21,320 kg/year from commercial and institutional sources. The per capita plastic waste generation rate was estimated at 0.452 kg/person/year.

The composition analysis revealed that the dominant plastic waste fractions were:

Plastic bags and films (42%)

Plastic bottles and containers (25%)

Plastic sachets and packaging (18%)

Other plastic items (15%)

This highlights the prevalence of single-use and short-lived plastic products in the waste stream, indicating the need for targeted interventions to address these problematic plastic items.

Plastic Waste Quantification

Table 2 provides a clear and organized summary of the key data points and calculations involved in the plastic waste quantification exercise for Ughelli.

Table 2: Key Data Points and Calculations of Plastic Waste Quantification

Category	Metric	Value
Household Plastic Waste Generation	Average plastic waste per household per day	0.75 kg
	Number of households sampled	500
	Average household size	4.2 persons
	Extrapolated plastic waste generation per day from households	375 kg/day
	Extrapolated plastic waste generation per year from households	136,875 kg/year
Commercial and Institutional Plastic Waste Generation	Average plastic waste per commercial establishment per week	3.2 kg
	Number of commercial establishments surveyed	100
	Average plastic waste per institutional establishment per week	1.8 kg
	Number of institutional establishments surveyed	50
	Extrapolated plastic waste generation per week from commercial and institutional sources	410 kg/week

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	Extrapolated plastic waste generation per year from commercial and institutional sources	21,320 kg/year
Total Plastic Waste Generation	Total plastic waste generation per year	158,195 kg/year
Plastic Waste Generation per Capita	Plastic waste generation per person per year	0.452 kg/person/year

Table 2 presents detailed data on the generation of plastic waste in Ughelli, Delta State, Nigeria, which was a critical input for the subsequent cost-benefit analysis. The household plastic waste generation data shows that the average household in Ughelli produces 0.75 kg of plastic waste per day. Based on a sample of 500 households with an average size of 4.2 persons, the extrapolated total plastic waste generation from households is 375 kg per day, or 136,875 kg per year. In the commercial and institutional sectors, the survey data indicates that the average commercial establishment generates 3.2 kg of plastic waste per week, while the average institutional establishment generates 1.8 kg per week. Extrapolating from the 100 commercial and 50 institutional establishments surveyed, the total plastic waste generation from these sources is estimated at 410 kg per week, or 21,320 kg per year. Aggregating the household, commercial, and institutional plastic waste figures, the table shows that the total plastic waste generation in Ughelli is 158,195 kg per year. Dividing this by the population, the plastic waste generation per capita is calculated to be 0.452 kg per person per year.

These quantification metrics provide a comprehensive baseline understanding of the plastic waste challenge facing Ughelli. The substantial household and commercial/institutional plastic waste generation totaling nearly 160 metric tons annually underscores the scale of the problem and the need for impactful mitigation strategies. The per capita figure of 0.452 kg per year also allows for comparisons to other communities and can inform targeted interventions. The detailed plastic waste quantification data presented in this table serves as a crucial foundation for the subsequent cost-benefit analysis, enabling the researchers to accurately assess the potential impacts and financial viability of the proposed plastic waste mitigation strategies for Ughelli.

ii. Cost-Benefit Analysis of the Mitigation Strategies

The result of the cost-benefit analysis evaluated for the four key plastic waste mitigation strategies is presented in Table 2.

Table 2: Cost-Benefit Analysis of Plastic Waste Mitigation Strategies

Strategy	Capital Costs (₦)	Operating Costs (₦)	Benefits (₦)	NPV (₦)	Cost-Benefit Ratio
Household Waste Segregation	150,000,000	120,000,000	350,000,000	80,000,000	1.35
Plastic Waste Collection and Recycling	175,000,000	112,500,000	400,000,000	112,500,000	1.50
Public Awareness Campaigns	60,000,000	40,000,000	150,000,000	52,500,000	1.28
Deposit-Refund Scheme	50,000,000	25,000,000	100,000,000	25,000,000	1.08

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The analysis commenced with a comprehensive assessment of the plastic waste generation in Ughelli, which was found to be approximately 150 tons per day. This substantial volume of plastic waste highlights the scale of the challenge facing the community and the urgent need for effective mitigation strategies. Among the four strategies evaluated, the plastic waste collection and recycling system emerged as the most financially viable option, with the highest net present value (NPV) of ₦112,500,000 and a cost-benefit ratio of 1.50. This indicates that for every naira invested in this strategy, there would be a return of ₦1.50 in benefits, making it a highly attractive proposition from an economic standpoint. The household waste segregation program also demonstrated strong financial performance, with an NPV of ₦80,000,000 and a cost-benefit ratio of 1.35. This strategy's ability to recover and market recyclable plastic materials, while reducing the burden on landfills, contributes to its favorable economic outcomes. The public awareness campaigns and deposit-refund scheme showed positive but lower NPV values of ₦52,500,000 and ₦25,000,000 respectively, with cost-benefit ratios of 1.28 and 1.08. While these strategies may have a smaller direct financial impact, they can play a complementary role in influencing behavioral changes and supporting the overall plastic waste management system.

Taken together, these findings provide valuable insights to policymakers and waste management authorities in Ughelli on prioritizing investments in plastic waste mitigation strategies based on their financial and economic viability. The community can maximize the returns on its efforts to address the substantial 150-ton-per-day plastic waste challenge. The plastic waste collection and recycling system still has the highest NPV and cost-benefit ratio, indicating it is the most financially viable option. The household waste segregation program is the second-best option, with a relatively high NPV and cost-benefit ratio. The public awareness campaigns have a moderate NPV and cost-benefit ratio, suggesting they are also beneficial but less financially attractive than the first two strategies. The deposit-refund scheme has the lowest NPV and cost-benefit ratio among the evaluated strategies, making it the least financially viable option in the short term.

CONCLUSION

This study has undertaken a comprehensive cost-benefit analysis to evaluate the financial viability of four key plastic waste mitigation strategies proposed for implementation in Ughelli, Delta State, Nigeria. The findings provide valuable insights to policymakers, waste management authorities, and other stakeholders on the relative merits of each intervention from an economic perspective.

The initial assessment found that the Ughelli region generates approximately 150 tons of plastic waste per day, underscoring the scale and urgency of the plastic pollution challenge facing the community. Against this backdrop, the cost-benefit analysis was conducted to determine which strategies would be most financially feasible to implement.

The results indicate that the plastic waste collection and recycling system and the household waste segregation program are the most financially attractive options, with positive net present values (NPVs) of ₦112,500,000 and ₦80,000,000 respectively, as well as favorable cost-benefit ratios of 1.50 and 1.30, respectively. These strategies demonstrate the strongest potential to generate long-term financial returns that outweigh their upfront investment and

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ongoing operational costs. The public awareness campaigns and deposit-refund scheme for plastic bottles and containers also showed positive NPVs of ₦52,500,000 and ₦25,000,000, with cost-benefit ratios of 1.28 and 1.08 respectively. While these strategies may have lower financial returns compared to the collection/recycling and segregation programs, they still possess economic merit and could play a complementary role in a comprehensive plastic waste management framework.

Considering the considerable environmental and public health challenges posed by plastic waste in Ughelli, implementing a combination of these strategies with a focus on the top-performing options would be a prudent approach. By prioritizing financially viable interventions, policymakers can mobilize resources more effectively and ensure the long-term sustainability of plastic waste mitigation efforts in the region. It is therefore recommended that further studies be conducted to assess the social and environmental impacts of these strategies, as well as explore potential synergies between them. Integrating financial, social, and environmental considerations will be critical in developing a holistic and impactful plastic waste management plan for Ughelli and other similar communities in Nigeria.

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