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Research Article

Estimation of plastic production, consumption, and waste generation in Nigeria: 2020 to 2050

Lukman ANIMASHAUN[1], Adekunle YEKINNI[1], Kabiru OLAIYA[1] Omotayo OGUNYEMI[1], Philip ADEWUYI[2*]

[1]Lagos State University of Science and Technology, Department of Mechanical Engineering, Ikorodu, Lagos State, Nigeria
[2] Wigwe University, College of Engineering, Isiokpo, Rivers State, Nigeria

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ABSTRACT

Global utilization of different types of plastics has been increasing over the years due to its many useful properties. However, disposal of plastic waste has been a challenge all over the world and Nigeria is not an exception. As the most populous country in Africa, Nigeria is among the highest consumers of plastic products. Plastic waste generation was considered using three different scenarios that considered forecasted gross domestic productions up to 2050. The results indicated that plastic production rate in Nigeria is linear as against plastic consumption rate which is exponential. The result estimates from 2020 to 2050 revealed that plastic consumption in Nigeria doubles every 9 years which was validated using the doubling time equation. However, substantial reduction was achieved if enhanced plastic waste management technologies are adopted. Further reduction is achievable through reuse or recycle and implementation of hierarchical waste management strategies.

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INTRODUCTION

Widespread consumption of packaged beverages and potable water consumption has been growing in developing countries and Nigeria's case is not an exception. Packaged water in sealed plastic bottles or sachet nylon has overtaken drinking water from water taps [1]. Plastics for packaging began to gain popularity in the 1960s which are used for consumer-packaged goods due to their low cost, chemical stability, lightweight, and ease of mass production [2]. Categories of plastics are natural plastics, semi-synthetic plastics, synthetic plastics, thermoplastics, and thermosetting plastics. Natural plastics are plastics made from polymers that occur in nature and can be extracted such as pectin, silk, wool, cellulose, proteins, and so on [3]. Semi-synthetic plastics are plastics obtained from a chemically altered natural polymer material, such as casein, cellulosic plastics, and vulcanized rubbers. On the other hand, synthetic plastics are entirely laboratory-made by converting monomer organic molecules to polymer molecules through a process known as polymerization to produce plastics with different properties. The different synthetic plastic materials can be polyethylene terephthalate (PET), Polypropylene (PP), High-Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low-Density Polyethylene (LDPE), and Polystyrene (PS) [4]. Unwanted plastics (waste plastics) are increasingly arising as a source of environmental issues (plastic pollution) and health hazards to humans, animals, and marine organisms.

An essential classification of plastics is the degree to which

***Corresponding author.**
*E-mail address: solaadewuyi@gmail.com

the chemical processes used to generate plastics are reversible or not. These are thermoplastics and thermosetting plastics. Thermoplastics do not change chemically when heated, as they can be repeatedly molded. A few examples are; Polystyrene (PS), polypropylene (PP), polyethylene (PE), and polyvinyl chloride (PVC). On the other hand, thermosetting plastics of 'thermoset', polymers, can melt and take shape only once: after they have solidified, they stay solid. When reheated, thermosets decompose rather than melt. In the thermosetting process, an irreversible chemical reaction occurs [5].

Thermosetting plastics not only have higher resistance to heat degradation and chemical attack but also have enhanced mechanical strength and hardness which upon heating normally decompose before melting. An example of thermosetting plastics is polyethylene terephthalate (PET) bottles as thermoset plastics. PET consists of polymerized units of the monomer ethylene terephthalate, with repeating (C10H8O4) n units and has the number "1" as its resin identification code (RIC). PET is a very lightweight (Density between 1380 and 1455 kg/m3), colorless, semi-crystalline resin in its natural state and can be made semi-rigid to rigid. It acts as a good barrier to alcohol and solvents with strong and impact-resistant but becomes white when exposed to chloroform and also certain other chemicals such as toluene [6]. A summary of different types of plastics are shown in Table 1.

Table 1. Samples of recycled concrete aggregate incorporation of fly ash [25]

S/N	Thermosetting	Thermoplastics
1	Polyester	Polyethylene Terephthalate (PET)
2	Polyurethane	Poly Vinyl Chloride (PVC)
3	Epoxy	Polypropylene (PP)
4	Bakelite	Low Density PolyEthylene (LDPE)
5	Urea-Formaldehyde	High Density PolyEthylene (HDPE)
6	Melamine	Poly Vinyl Acetate (PVA)
7		Polystyrene

In 2017, the global production of plastic was about 348 million tons [7] with the packaging industry utilizing about 30% of the produced plastics [8]. The increased consumption of plastics is attributed to the rapid urbanization and economic development in developing regions of the world [9]; [10]. The most populous country in Africa is Nigeria with a population of more than 200 million people [11]. It consists of 36 states with over 51.5% (86.7 million) of the population choosing to live in urban areas [12].

Nigeria's population is now predicted to expand at a pace of 2.86 percent each year and is expected to double around 25 years' time [13]. Despite efforts to minimize the effect of poor waste management in Nigeria, there are still challenges in the core areas of production, consumption, and pot-consumption management. Importation of high volume of plastic product is still being done in Nigeria which poses a major challenge to waste management authorities in Nigeria. The Nigerian economy, as it were, favors linear economy and efforts should be geared toward a more robust circular economy which encourages long lasting usage and re-use of materials thereby reducing the amount of waste generated [14], [15]. This can be closely correlated with the rate of rise in municipal solid waste (MSW) in general and plastic wastes which has now involved policies that brought private sector into waste management programs through public-private partnerships as currently being witnessed across states in Nigeria though highly politicized [16], [17]. However, it is yet to be established the doubling time for plastic consumption in Nigeria.

A study of inventory of plastics imports into Nigeria indicated that less than 12% of the resulting waste from about 17,620,000 tons of total amount of plastics imported in primary form and 23,400,000 tons of newly produced plastic and plastic components enters the recycling stream [18]. Waste plastics not only present a great challenge to the environment through marine litter and pollution but also waste management and resource recovery. Unwanted plastics currently creates problems not only for people and the environment, but also economically for Nigeria, which could be attributed to high rates of improperly handled plastic garbage and inadequate access to cutting-edge recycling facilities. Fossil hydrocarbons are the primary source of the monomers used to produce plastics, and the end products are not biodegradable which accounts for their high environmental persistence [8].

The biggest danger to reducing plastic pollution and hazards is the unsustainable manufacture and use of virgin (primary) plastic polymers. Global plastics effort has been concentrated on midstream and downstream measures on waste management and product design, ignoring upstream measures that address the manufacturing and consumption of virgin plastics. There have been many studies on production and consumption of plastics in Nigeria, but few studies have considered the growth in production and consumption of plastics in the next 50 years. The objectives of this study are to develop a growth rate model for plastic production and consumption in Nigeria. In addition, the research will investigate waste plastic products based on different scenarios in Nigeria. Results from the study is expected to inform and guide the Nigerian government to plan for the evolving threat of plastic waste and its associated economic loss to the economy.

MATERIALS AND METHODS

This study will consider a multi-dimensional approach that involves identifying and synthesizing available secondary production and consumption weighted data available from Euromap (2016) on Plastics Resin Production and Consumption in 63 Countries Worldwide (2009-2020). A graphical plot of weighted data of plastic production and con-

sumption is obtained from 2009 to 2020 as shown in Table 1 [19]. The curve or line of best fit from the exponential growth model is determined using doubling time technique to give the equations that would enable the prediction of future consumption of plastics in Nigeria. This is important for the government and citizens to understand the enormous task of controlling unchecked use of plastics before run-away waste plastic wastes pose environmental danger to the society.

In order to understand the nature of plastic consumption growth rate, this study will consider determining the doubling time for the plastic consumption in Nigeria. In this study, it will be considered as the time it takes for the consumption of plastics to grow over time when the relative growth rate is assumed to be constant [20]. When applied to the constant growth in consumption of a resource, the total amount consumed in one doubling period equals the total amount consumed in all previous periods.

For future projections of plastic waste, previous research studies had employed the scenarios-based method by assuming three scenarios [21]. Scenario A will consider the case of business-as-usual where the mismanaged fraction is maintained into the future years as reported by [18] and [22]. In scenario B, the mismanaged fraction K(t) is varied over time from an initial value K(t0) using Equation 1:

$$K(t) = K(t_o) + e * [X_c(t) - X_c(t_0)] \quad (1)$$

The value of e is taken as (- 0.00313). Since e is negative, a growth in per capita GDP (Xc) from year 2020 to 2050 will result in the decrease of mismanaged fraction. The predicted growth in per capita GDP for Nigeria that will be used for this estimation is obtained in the works of [23] as shown in Figure 1.

This assumed that as the economy grows, plastic waste management infrastructure improves. In scenario C, the assumption will not only be on the improvement in plastic waste management, but also reduction in plastic use as the economy improves. In this study, scenario C will be considered to take place in two stages. One stage is for scenario C, taking place in 2020 with 10% reduction in waste plastic fraction in MSW instead of the 12% from 2020 to about 2040 which further reduces to 5% of the MSW [18].

RESULTS

Growth Pattern of Plastic Production and Consumption

The results of plastic production and consumption from 2009 to 2020 is shown in Table 2. A graphical representation of the changes in plastic production and consumption in Nigeria between 2009 and 2020 is shown Figure 2.

The results in Figure 2 indicated that plastic production in Nigeria is proportional to yearly changes that can be mathematically represented by the linear mathematical expression as shown in Equation 2, where x is in years.

The Chi squared distribution (R2) for this equation is: R2= 0.9549. This model equation can be used to predict plastic production in Nigeria into the future years. On the other hand, results in Figure 2 shows that yearly plastic consumption has a model equation that is an exponential function as shown in Equation 3, where x is in years. The Chi squared for this equation is R2= 0.9972. This will enable plastic consumption in Nigeria to be predicted in future years. These results will be used to predict plastic waste under different scenarios. In addition, energy used in producing the plastics and processing the associated waste alongside the carbon footprint will be assessed.

$$Plastic\ Production\ (PP) = 25.147x + 223.88 \quad (2)$$

$$Plastic\ Consumption\ (PC) = 621.55\, e^{0.076\,x} \quad (3)$$

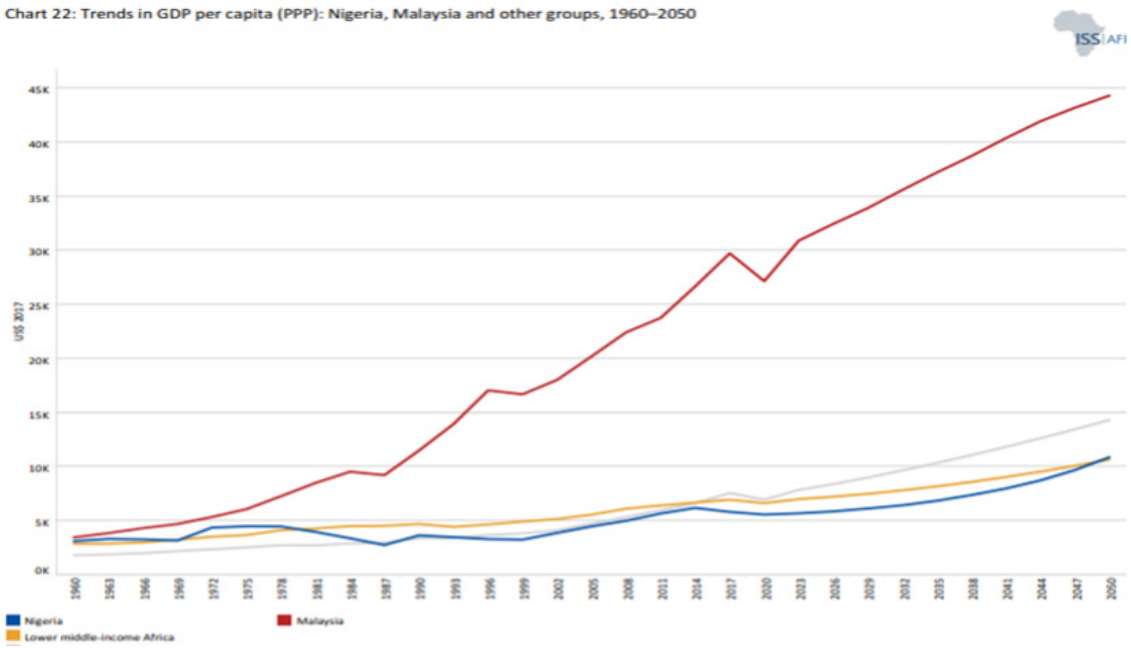

Figure 1. Predicted per capita GDP growth rate for Nigeria [23]

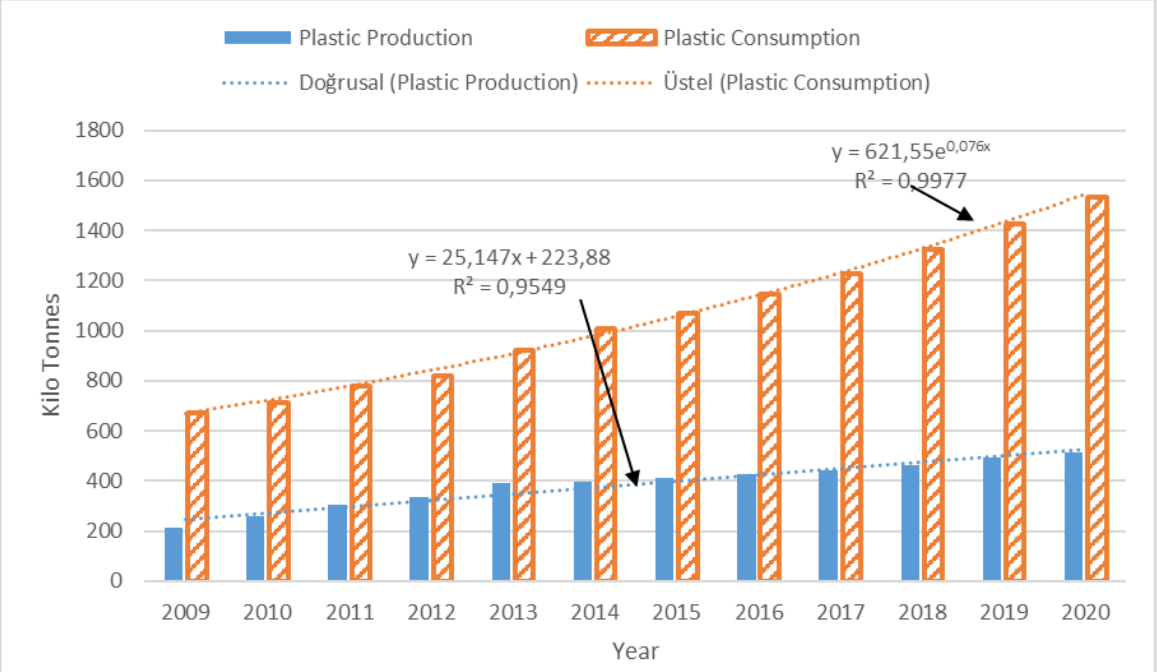

Figure 2. Changes in plastic production and consumption

Table 2. Plastic production and consumption in Nigeria between 2009 and 2020 [19]

Year	Plastic Production	Thermoplastics
2009	213	672
2010	260	713
2011	303	780
2012	335	821
2013	390	921
2014	396	1010
2015	411	1072
2016	428	1146
2017	442	1229
2018	462	1322
2019	495	1424
2020	513	1533

The projection of plastic production and consumption from 2020 to 2050 using Equation 2 and Equation 3 was based on the value of the variable x is obtained in order to account for the years between 2009 and 2020 by the addition of 12 to every successive three years. The natural exponential growth rate of plastic consumption shown in Equation 3 indicated a growth rate of about 7.6 kg/ppd in comparison to 7.9 kg/ppd obtained in the research study of [22, 8, 24]. The results of plastic production and consumption from 2020 to 2050 based on Equation 2 and Equation 3 is shown in Table 3. This indicated that plastic consumption in Nigeria will likely double every 9 years. On the other hand, theoretical doubling time T_d can be evaluated for an exponential function of constant growth rate a, if the consumption at time T_1 is Y_1 and Y_2 in future time T_2.

$$If\ Y_1 = Y_o . e^{aT_1}\ and\ Y_2 = Y_o . e^{aT_2}$$

$$\text{But } \frac{Y_2}{Y_1} = e^{a(T_2 - T_1)}$$

For the consumption to double, $Y_2 = 2 . Y_1$ or $\frac{Y_2}{Y_1} = 2$

If the doubling time is $T_d = (T_2 - T_1)$, then $e^{aT_d} = 2$

In Equation 2, a is obtained as 0.076 or 7.6%.

Hence, $T_d\ (Doubling\ Time) = \frac{\log 2}{a} = \frac{0.6931}{a} = \frac{0.6931}{0.076} = 9.12 \sim 9\ years$

What determines the doubling time is the growth rate which has an inverse relationship.

The projected results of plastic production and consumption based on Equation 2 and Equation 3 are shown in Table 3.

It is obvious that plastic production would continue to increase due to population growth and costly alternative to plastic-based products notwithstanding the growth in plastic industry in terms of metrics that favor the economy of Nigeria. Meanwhile, as the rate of plastic consumption increases exponentially, it implies that robust waste management policies and strategies should be in place and implemented meticulously in order to further reduce issues around environmental degradation.

Table 3. Plastic production and consumption forecast for Nigeria

Years	Projection for Plastic Production (kilo tons)	Projection for Plastic Consumption (kilo tons)
	$P_p = 25.147x + 223.88$	$P_c = 621.55e^{0.076x}$
2020	526	1,547
2023	601	1,943
2026	677	2,441
2029	752	3066
2032	827	3851
2035	903	4838
2038	978	6077
2041	1054	7632
2044	1129	9588
2047	1180	12043
2050	1255	15127

Table 4. Plastic waste under different scenarios

Years	Projected Plastic Production Million Tons	Projected Plastic Consumption Million Tons	GDP per capita ($)	Scenario A	Scenario B	Scenario C
				Business-as-usual Million Tons	K(t) 10% / K(t) Million Tons	10-5%/K(t) Million Tons
2020	0.526	1.547	5600	1.361	1.361	1.361
2023	0.601	1.943	5700	1.710	1.153	1.134
2026	0.677	2.441	5900	2.148	1.119	0.924
2029	0.752	3.066	6100	2.698	1.109	0.924
2032	0.827	3.851	6400	3.389	1.064	0.887
2035	0.903	4.838	6900	4.257	0.976	0.813
2038	0.978	6.077	7400	5.348	0.976	0.407
2041	1.054	7.632	8000	6.716	0.939	0.387
2044	1.129	9.589	8700	8.438	0.887	0.370
2047	1.204	12.043	9700	10.598	0.755	0.315
2050	1.280	15.127	10900	13.312	0.666	0.278

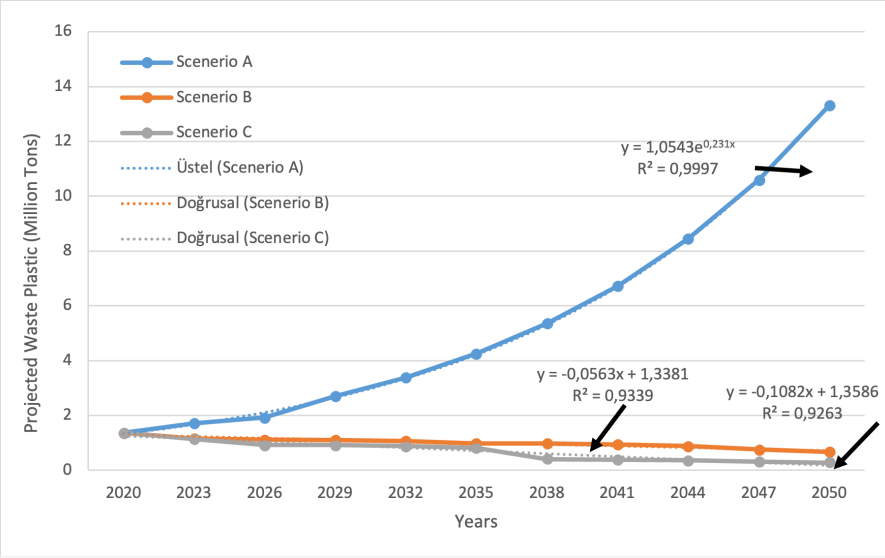

Figure 3. Comparative plastic waste management under different scenarios in Nigeria

Analysis of Different Scenarios for Plastic Waste Management

The results of different waste plastics management over three years' interval using 2020 as reference is shown in Table 4. The result indicated that unmanaged plastic waste in Nigeria will top other African countries by 2050 as suggested by [21].

To better understand the various changes caused by different scenarios used for municipal waste plastic management, a graph depicting each scenario from 2020 to 2050 is presented in Figure 3. In scenario A (unmanaged plastic waste), plastic waste is generated exponentially. This result is similar to that projected for Africa in the study of Laurent [21].

Plastic waste management in scenario A was observed to give an exponential increase as years progressed, unlike scenario B and C that was close to decreasing linear functions of time. The results show that substantial reduction in plastic waste (about 97%) can be achieved if plastic waste management in Nigeria can adopt scenarios C in comparison to unmanaged plastic waste (Scenario A). However, this greatly depends on the predicted growth in per capita GDP for Nigeria.

DISCUSSION

Between the years 1990 and 2017, Nigeria was estimated to have 15.77 Mt of plastic in primary form and 4.099 Mt of plastic as plastic products [19]. In this study, the result of plastic consumption in Nigeria indicated an exponential increase, unlike the linear function obtained for plastic production with a growth rate that is about 4% lower than that forecasted in the works of [22]. Globally, there has been a steady increase in the amounts of plastics consumed annually and Nigeria is not an exception. In this study, plastic production was estimated to increase to about 1.255 million tons by 2050 against 15.127 million tons of plastic consumption. With regards to global urbanization and economic development, the rise in plastics consumption in Nigeria will utilize more natural resources to meet the growing demand for plastics. The exponential demand for plastics obtained in this study is similar to that projected for the rest of the African countries as outlined in the works of [21]. In addition, the resulting waste plastic was shown in this study to grow by 90% in 2025 if the present level of plastic waste management in the country is maintained.

The use of plastic in consumer products has been linked to adverse environmental effects, such as greenhouse gas emissions, pollution of the air, land, and water, depletion of water resources, and the creation of marine debris in the world's oceans [25]. Results from this study reveals the necessity for improved plastics waste management by the adoption of scenario C which reflects a reduction in plastic demand per capita with fraction of plastic in municipal solid waste capped at 10% from 2024 to 2035 and 5% from 2035 to 2050. Hence, in Nigeria substantial reduction in plastic waste in our society requires the simultaneous improvement of plastic waste management and reduction of plastic use.

This indicated that if plastic waste is not controlled, human health, environment and economic loss could result. At this level of GDP and population density for Nigeria, the result of this study is significant because it can assist policy makers in identifying priority states like Bayelsa, Lagos, and Katsina. Additionally, future projections in this study provides dataset which can help in establishing goals to lower plastic waste production and restrict discharges into the environment through the various local governments, states, and the country. Presently, more than one-third of the world's MPW generation comes from China and India, whose GDP growth rates are predicted to be over 4% until the middle of the 2020s and beyond. One of the ways of enhancing plastic waste management in the country is to adopt the 3R of strategic solid waste management (Reduce, Reuse and Recycle) as being advocated through circular economy where materials are fully utilized as long as possible thereby serving as a means of creating new products which are less resource intensive unlike the linear economy, though, leading to rapid industrialization but turning products to waste at a faster rate which degrade the environment and natural resources [26], [27].

Recycling is one of the best solutions to managing waste plastic from an environmental and socio-economic perspective. It is more efficient than landfills and incineration [28]. There are two broad methods of recycling plastic waste. These are primary recycling and secondary recycling or Mechanical recycling. Primary recycling is defined as the process of creating same or comparable plastic items and is sometimes known as the "Reuse strategy" that entails the repurposing of materials. An example of primary recycling is where plastics are recovered from postconsumer and used in the production of new plastics. On the other hand, a process of turning plastic waste into secondary raw materials or products through mechanical recycling and maintaining the chemical structure of the materials mostly intact or the transformation of plastic waste into variously characterized items. The other secondary methods for consideration of plastic waste recycling are: Pyrolysis/thermal degradation, Catalytic degradation and Gasification.

The recycling of plastic waste has numerous benefits. These are: energy conservation, greenhouse gas emissions reduction, reduce the cost of using virgin raw materials, strengthen the nation's export standing and GDP, preserves non-renewable resources like gas and oil, offers millions of people and families in developing nations with a means of subsistence. Recycling plastic waste products can be seen as a business opportunity and used as a solution to creating health and wealth. One economic benefits of plastic waste recycling can be seen in plastic recycling to polyester used as a replacement for cotton clothing [29]. In the construction industry, recycled waste plastic materials are utilized as reinforcement or additives to make composite materials and acts as permanent joint in adhesive bonding to the surfaces of objects [30]. The various benefits of plastic waste recycling can transform plastic waste management from the present linear state to circular economy.

Presently in Nigeria, there are very few wastes recycling

plants. Most plastic waste ends up in the landfills or are incinerated or outright disposal in the drains, rivers, lagoons and the ocean. However, emerging trends indicates the advent of scavengers and Private Sector Participating (PSP) waste collectors in collaboration with Waste Management Authorities of some States in the country. These agencies are yet to adopt the waste hierarchy guidelines in their approach to plastic waste management as shown in Figure 4.

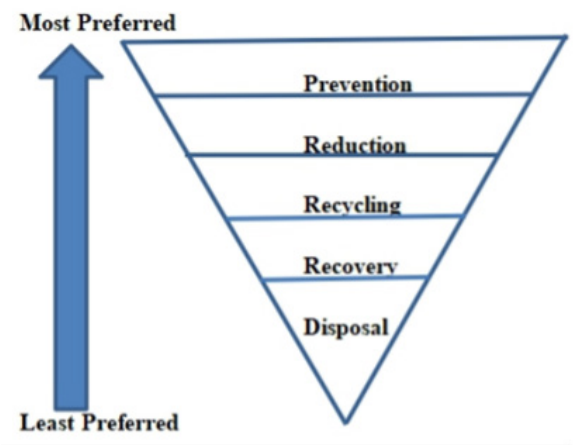

Figure 3. Waste management hierarchy [31]

CONCLUSIONS

This study has used secondary plastic production and consumption data in Nigeria to formulate a model equation for production and consumption growth rate from 2020 to 2050. The study was able to estimate the doubling time of plastic consumption in Nigeria by using doubling time formula and not rule of 70 method. Assumptions made were that good waste management programme is in place and incentives are provided to discourage the populace from the use of plastic materials. Plastic waste management under three scenarios was considered to provide policy makers different ways of tackling the threats arising from uncontrolled plastics waste management and consumption such as proper monitoring of the municipal waste management, disposition, and recycling strategies. The growth of plastic production in Nigeria as the number of years increases is a linear function. Plastic consumption growth rate on the other hand is an exponential function of time as the number of years increases. The consumption of plastics in Nigeria was found to double every nine years under the business-as-usual scenario, where the mismanaged fraction is maintained. This study recommends the adoption of scenario C model as projected into the future years would give about 98% plastic waste reduction if the immediate enhancement of plastic waste management infrastructure and reduction of use of plastic strategy is adopted and implemented.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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